2.

Let the video be your guide: A case study of video-based design research*

Abstract

In this article the iterative process of a design-based research project using video as one of the data sources will be reported. During the iterative design and implementation processes video recordings of teachers and students were used to provide guidance through the practical and conceptual changes. The video was an indispensable data source. Without it there would have been no possibility of 'seeing' how the curriculum project was enacted nor what the explanations for several results based on other data might be. We explain how our video data guided our academic analysis at three levels, the baseline level, the methodological level and the meta-level. With hindsight we are able to see that the extensive use of video data co-determined the course of the research trajectory in ways that would not have been possible with quantitative data alone. Through the use of video data we attempted to find an answer to questions of codified knowledge in knowledge-rich workplaces, simulated in vocational education. On the basis of our research experiences we conclude that video observations are indispensable if our aim is not only to improve theory and practice but also to reflect on the design of the method itself; especially if design research is regarded as open-ended, and the agency of participants is valued.

* This chapter will be submitted as an article.

Introduction

This study reports on the iterative process of a design-based research project using video as one of the data sources. The overall research question of the project was: *Do students, who participate as model designers in a process of guided co-construction with an expert (teacher) and peers, show better learning outcomes than students who learn to work with ready-made models provided by the teacher?*

During the project, between 2005 and 2010, six schools with over 30 teachers and 200 students were studied. More than 100 hours of video data were gathered[2]. In what follows a post hoc analysis of video data use is described with the aim of determining the value and role of video in our research; thus showing "how we came to know" (Goldman, 2007, p. 29). The research project was design-based (Barab & Squire, 2004; Shavelson, D.C. Phillips, Towne, & Feuer, 2003; The design-based research collective, 2003), started with the design of an educational curriculum project and ended with an experiment at four schools. We collected data on seven schools in three stages over three years. Figure 2.1 shows an overview of the research time-line.

As is often the case with this kind of research many changes and reorientations were made along the way. We had to take design decisions before and during the implementation of the intervention (Cobb, Zhao, & Dean, 2009). At the beginning of the research project there was little experience in the Netherlands concerning research in workplace simulations in preparatory senior secondary vocational education (VMBO)[3], and no guidelines for video research in the learning sciences had yet been formulated (Derry et al., 2010). During the iterative design and implementation process video recordings of teachers and students were used to guide us through the practical and conceptual changes. In addition, video helped us develop our theoretical framework and guiding principles (Terwel & Walker, 2004).

With hindsight, the use of video played a significant role in that it guided research development at three levels. Starting with educational practice, video helped us to see and understand how the designed curriculum project worked in the classrooms. We call this the baseline level, since actual classroom practice was the unit of analysis. The designed educational intervention could be (re)viewed

2 This is an estimate since almost all video was digital and compression methods have changed, it is hard to calculate the actual hours of classroom footage.

3 Preparatory senior secondary vocational education is the official English translation used by CEDEFOP for Dutch VMBO. It is pre-vocational education for 12-16 year old students. About 60 % of Dutch students attend this type of education. VMBO was introduced in 1998. From her onward we will use VMBO.

in action. The video data were therefore the visual tool for the primary analysis. In our case it supported the analysis of how the teachers guided the students and how students' understanding developed. The second level was methodological. At this level the video informed us how the implementation and methods developed within the separate stages and over the different stages. We divided this level into two sub-levels. The first concerned the way in which our intervention changed through the agency of the participants within one stage, as as well as how the video data through the stages showed our intervention changes from one stage to the next. The second data sub-level describes how the type of data changed and thus the type of analysis. Informed by both the baseline and the methodological level, our perspective also changed. This was visible at the meta-level. The video data itself changed over time. From an intensive and close look at a few participants it developed into a more distant view of many participants. In other words, not only had the method changed but our view of what we actually needed to know for answering the main research questions had also shifted. In the following sections we will address each level in greater detail.

The theoretical framework will be followed by a discussion of the three research stages (the baseline level). Next, we will take the reader through several changes of the intervention design and the methodological approach during the research project (the methodological level). Then, we address the question of how we adjusted our perspective (the meta-level). The following questions will be answered for each level:

a. What was the value of the video in this design research?
b. To which adjustments did the video data lead?
c. How were these changes visible in the video data?

Finally, in the discussion, the answers to the questions will be compared to the challenges formulated by Derry et al. (2010), especially those on the selection and analysis of video research in the learning sciences.

Theoretical framework and method

In vocational education students both design and construct real products in collaborative groups. Problem that need to be solved arise in the design process as well as in the actual construction. Models can be used to anticipate possible problems and their solutions. For example, on the basis of a model angles can be calculated in a drawing to determine how pieces of steel should be sawn off, rather than by trial and error only to find that the steel parts cannot be put together. Here the formula used to calculate the angle functions as an orientation tool.

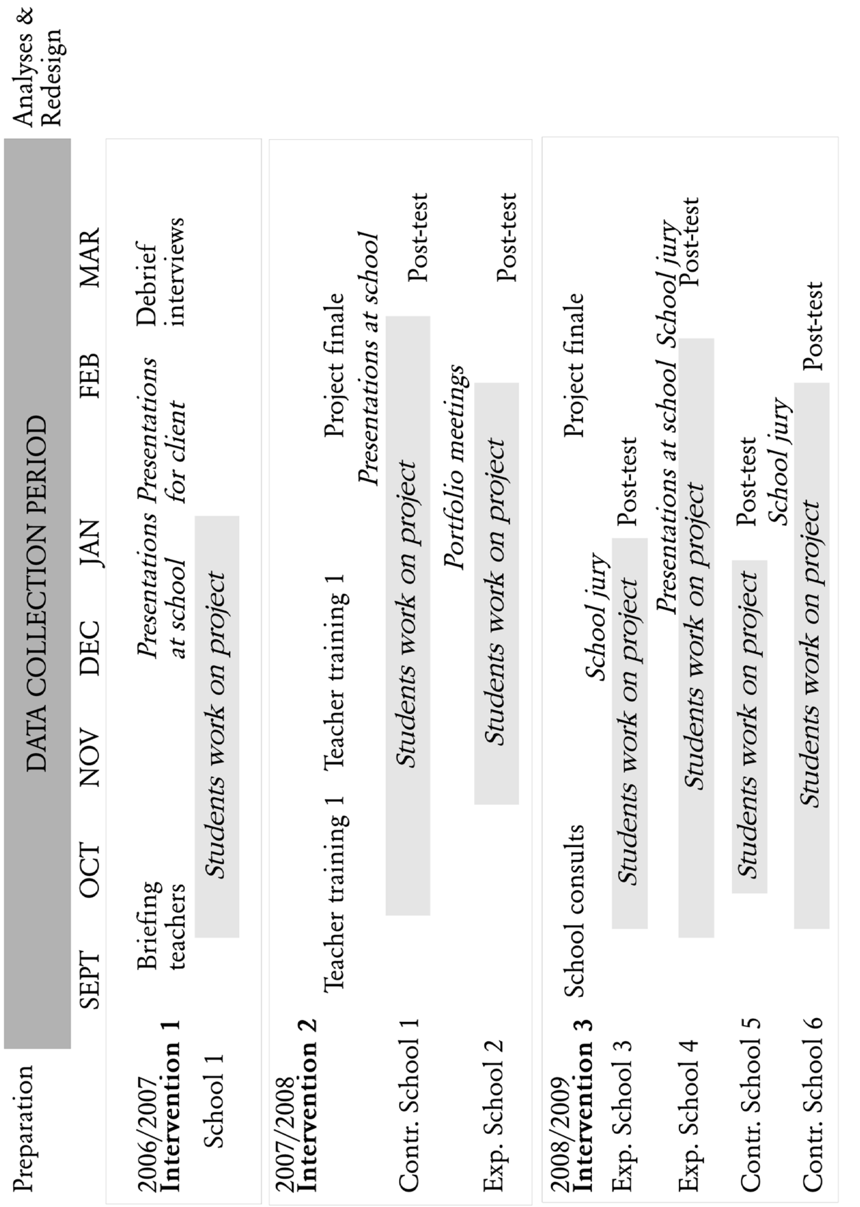

Figure 2.1 Time-line of the research.

By collaboratively reflecting on, and improving the production process group members learn to understand the mostly tacit rules and codes of the workplace as well as the hidden knowledge it involves. Models (as prototypes) could function as tools of communication and focus on the anticipated production process and thus help students think ahead and (collaboratively) reflect on their own process (Van Schaik, van Oers, & Terwel, 2010a; Tuomi-Gröhn, 2003).

The challenge to schools lies in formulating assignments that are meaningful for the students and realistic for their future work (Tuomi-Gröhm & Engeström, 2003; Volman, 2006). At the same time, such assignments should also result in highly qualified learning outcomes that enable students to recontextualize and translate their knowledge and skills from the classroom to the workplace and vice versa. Guile and Young (2003) suggest knowledge-rich workplaces to support the recontextualization of situated knowledge into codified knowledge.

The important role of the teacher(s) in our project, namely guiding the students in knowledge acquisition and practical understanding, also includes introducing students to the mathematical practice of modeling. It is the teachers' role to identify what is 'mathematical' in the practice of the workplace, to recognize the emergent need in students for mathematical tools and relate such need to the practice of (mathematical) modeling (Van Oers, 2001). Providing models alone is not sufficient to understand the use of models as tools; rather, conditions should be shaped that focus "… on the hidden rules and assumptions in the tools." (Van Oers, 2001, p.81). Therefore, the guidance of the teacher should promote this understanding by helping students co-construct the meaning of the models. Put differently, 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). Research has shown that the instructional strategy of guided co-construction may lead to a better understanding of mathematics and modeling than a strategy based on models that are simply provided (Doorman, 2005; Terwel, Van Oers, Van Dijk, & Van den Eeden, 2009; Van Dijk, Van Oers, & Terwel, 2003).

From the theoretical framework above four guiding principles were formulated for the design of innovative practices. First, the student assignments had to be meaningful; that is, resembling workplace tasks related to students' possible future vocations. Secondly, assignments had to be complex enough to enable students to learn more than just vocational skills. Real workplace activities could increase the need for specific knowledge and skills and subsequently provide opportunities for learning. Following Guile & Young (2003), such a workplace may be characterized as a knowledge-rich workplace (p.73). They are assumed to engage students in meaningful activities and at the same time promote subject matter learning (such as mathematics; see Kent, Noss, Guile, Hoyles, & Bakker, 2007). The product to be constructed should be new to the students and challenging in such a way as to require the creation of models, plans and calculations. Such a process might lead to a recontextualization of previously learned codified knowledge in a new situation. Third, the students had to collaborate on the cooperative construction, as well as there mutual communication while focusing and reflecting on their models. Fourth, the schools had to be adapt and adjust the intervention to their local conditions. The curriculum project therefore needed to be adjustable while the core of the assignment goals had to be maintained.

For our study we designed an educational curriculum project for vocational education. Students had to design and construct a tandem tricycle for approximately five-year old elementary school pupils. Teachers were to guide their students in the design and construction process. For about 10 weeks students, together with the teachers, worked at this construction task in groups of three to five in large school workplaces, while solving problems and gaining new knowledge to get the work done. We closely studied the way in which teachers guided the students and tested the knowledge gained during that process. The data came from three separate stages: at the first stage one initial design of the curriculum project was implemented at one school and qualitatively analyzed as a case study (Van Schaik et al., 2010a); the curriculum project was redesigned on the basis of the results. The following two stages consisted of two experiments. In these experiments the redesigned curriculum project was tested, at two schools and four schools respectively. At the latter stages we collected video observations in addition to test data on knowledge, understanding and student characteristics.

The approach of the complete research project could be characterized as design-based (Barab & Squire, 2004; Cobb, Confrey, diSessa, Lehrer, & Schauble, 2003; The design-based research collective, 2003). This methodological approach needs further explanation.

Since our theoretical framework had a Vygotkskian foundation, according to Bell (2004), the project could be labeled cultural psychology design-based research which "… .. attends to the local cultural–historical foundations of development and learning as it is promoted and transacted through patterned interactions between individuals and artifacts" (p. 247). As the teachers were constantly involved in the development of the intervention together with the researchers the concept of mutual appropriation may be the proper way to understand our iterative design process (Downing-Wilson, Lecusay, & Cole, in press). For Engeström (2009) acknowledging the role of the teachers as actors who in the end shape the intervention is one of the characteristics of research based on a Vygotskian foundation. In addition, since our aim is also to "… generate *intermediate* concepts and solutions that can be used in other settings as tools ..." (Engeström, 2009, p. 321, italics added), and given that such solutions are not known ahead of time, our methodology could be characterized as a formative intervention.

The reason for using a video approach, not only in the case study but also in the two experiments, was that we aimed to analyze both the students' microgenetic learning trajectory and the development of the intervention (cf. Mercer, 2008). Using video in addition to to other forms of data, it was possible to identify "the changing participation of the students in group interaction" (Erickson, 2006, p. 181).

All in all we collected more than 100 hours of video data over the three research stages. The video data consisted of classroom data (including interviews supported by classroom footage) and co-design data (including member checking, cf. Stake, 1995).

After collection of the observation data, we looked for interactions on the way students used information and mathematical models and how the teachers assisted them in the use of such newly acquired tools when solving the problems they encountered. Three cameras were installed in the classroom: two fixed cameras and one hand-held camera. The fixed cameras recorded continuously while one of the fixed cameras also recorded the audio that was captured by means of a wireless microphone attached to the teacher. The third hand- held camera was operated by one of the researchers (always the same person), aiming to capture those interactions in which students and teachers together, or students by themselves, solved problems (for a more detailed description see van Schaik et al., 2010a; Van Schaik, 2009). In addition, we video-recorded the interviews with students and teachers held shortly after each observation, in addition to the training and participant-checking sessions.

The baseline level: The research narrative

In this section we describe the research narrative, which may be considered a brief summary of the overall research project processes. More detailed descriptions of the findings can be found in the reports of the separate studies (Van Schaik, et al., 2010a; Van Schaik et al., 2010b; Van Schaik et al., submitted a; Van Schaik et al., submitted b)

The research project started in November 2005 and lasted five years. The collaboration with teachers and schools started early in 2006 and is still continuing. After having defined our design principles (see above) we created two possible assignments for students. We proposed these to the first school and asked the teachers if they expected the students to be able to complete the

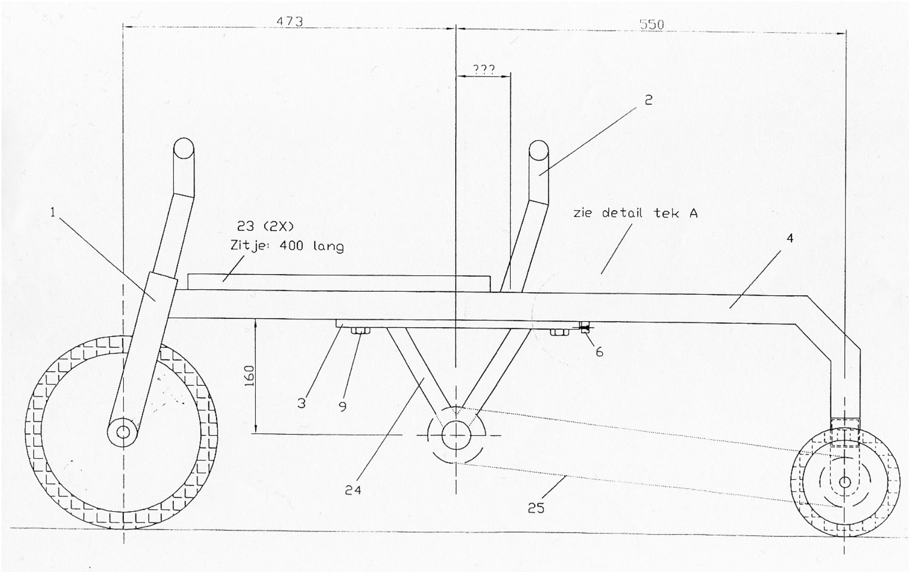

Figure 2.2 Technical drawing of students' design drawn by the teacher

assignments, and requested them to indicate which one they thought more feasible with regard to finishing the product and the opportunities for modeling. Together with the teachers we selected two construction assignments to be tested in a case study: a bicycle race game and a tandem tricycle. Each of these required about eight weeks (the duration of the school term), with at least a daily two hours' work on the assignment. After the case study analysis the tandem tricycle assignment proved to be more knowledge-rich, and was redesigned for the next interventions. An experiment was conducted at two schools and both the qualitative and quantitative data were analyzed. Next, based on the findings the curriculum project was redesigned, followed by a second experiment at four schools. In the next sections we report on the role of the video data in the outcomes of these three stages.

Case study

Initially, we went to the school with some propositions of assignments. In the assessment process two co-designed curriculum projects were studied. The projects took about eight weeks in the autumn of 2009. During that time we collected video data on the projects as enacted in the classroom and on interviews with students (n=15) and teachers (Van Schaik et al., 2010a; Van Schaik, 2009). In the latter video-stimulated interviews (Clarke, 2002) participants were shown video images of their own activities and were asked what happened. In the final interviews we had the students reflect on what they had learned and how the assignments were different from the ones they were used to. Teachers were asked what they thought the students had learned and how these assignments could be improved.

The analysis of the observational and interview data provided evidence that the knowledge in the simulated workplace remained situated. That is, the knowledge involved was not general in the sense that it could be recontextualized by the students to other situations or contexts. In addition, the knowledge and models were provided by the teacher as ready-made solutions (Figure 2.2 shows an example of a construction drawing by the teacher). In Video 2.1 examples from the video data supporting the findings are collated.

»ε Video 2.1 Video samples supporting case study findings[4,5]

4 »ε (ε from extra and the Greek word ε δον, to see) indicates an extra video sample which can be found at http://mvsjtbvo.video-research.eu after registration.

5 Informed consent was obtained from the parents by the schools, as the researchers only had contact with the schools.

After this first data analysis we went back to the teachers for a participant member checking. In this session we checked whether the teachers agreed with on our analysis, and how the curriculum project could be improved. Two practical issues were raised by the teachers. First, they suggested that, since one of the assignments (the bicycle race game) did not get finished, it would have been too difficult for the students to design a double transmission object (for the game to work, students had to come with a solution for at least two transmission problems). This was in line with our observation that the teacher provided the ready-made models. As one teacher put it:

Excerpt 1
Teacher: ... let alone [the students] having to make a construction drawing. They are simply not up to it. The drawings and sketches they make do not resemble a technical drawing. It think it is my job to make a drawing they can work with.

Secondly, the ‘client’ for the race game was a former teacher of the school and may not have been ‘real’ enough (the client for the tandem tricycle was a elementary school head). The tandem tricycle was regarded the better assignment to continue with. The main improvement in the project, according to the teachers, would be a better integration of the subject matter classes and the practice workplace. However they did not offer any suggestions as to how such integraton might be implemented.

We continued our analysis with the insights from these data and designed the next version of the curriculum project. We selected the tandem tricycle as the assignment and developed a guide for the teachers based on the experiences in the first case study. For the students there was one change: the product to be constructed should be a prototype for a contest. This would justify teachers in asking students to reflect on their process and production, using and exploring knowledge and models from science and mathematics. Thus, integration of subject matter classes might be established.

First experiment

In implementing the first project experiment at two schools (n=65) we received help from an experienced teacher trainer, who was specialized in mathematics. He led the sessions with the teachers, during which we co-developed and implemented the curriculum project at each school in accordance with the research conditions to which they had been assigned. We had an initial meeting with all participating teachers of each condition separately, during which the project’s significance for the students was explained, while the opportunities for modeling, based on the first study, were highlighted. During this session we used clips from the case study video data to illustrate what the intervention might look like. We asked the teachers how they thought they might implement the intervention. Their suggestions were worked out during the summer vacation, resulting in two separate programs, since we planned to conduct an experiment in a pretest posttest control group design. This was to mirror the difference between the conditions to be enacted: teachers in the control condition would provide models to the students, whereas teachers in the experimental condition would guide students in collaboratively constructing the models themselves. It should be noted that schools were assigned to the conditions depending on their current pedagogical practice, which we determined during school visits and subsequent meetings. The teachers were allocated to the condition that best fitted their customary approach to teaching (providing or guiding co-construction).

The implementation took place in the autumn and lasted 8-10 weeks. Each school fitted the curriculum project into their existing year planning, which explains the difference in duration. The teacher trainer visited the schools twice during the implementation to consult with the staff. In addition, we had a collective session for each condition half way during the implementation. Video data was collected in the same fashion as for the case study: three classroom cameras and video-supported interviews with both students and teachers. Moreover, we pre-and posttested the students on knowledge and modeling, and collected test data on their initial characteristics such as vocabulary, general intelligence and personality (Van Schaik, Van Oers en Terwel, 2010b).

The quantitative analysis of this intervention showed no difference between the conditions with respect to scores on the posttests on knowledge codified from the disciplines (maths and mechanics). However, as rated by modeling experts, the students in the experimental condition produced better models of their products. Interestingly, analysis of the video data showed that the students' models (i.e. the construction drawings) disappeared during the process of construction, and were no longer visible in the observations. Video 2.2 shows typical of week 3 and week 6 sequences at School 2, starting with week 3 sequences with students working on, and using their drawings, followed by week 6 sequences without drawings.

»ε Video 2.2 Typical week 3 and 6 sequences at school 2

Again we went back to the schools with these analyses of the test and video data to check whether our initial sense of what had been going on was confirmed by the teachers. These sessions were very different at the two schools. The teachers in the control condition, again, were very constructive and confirmed our first analysis. Their main point was that students should be taught how to draw and design on separate occasions, since they were patently incapable of doing that:

Excerpt 2
Teacher (control condition): [I] don't ask them to do the drawing themselves [the technical design model], because they simply can't.

The teachers in the experimental condition intimated that they had been skeptical from the start, since they thought students needed more guidance. Looking back at the video recordings of the training sessions from the start of the project onwards, we could confirm that the teachers had in fact been skeptical. However, at that time they did not express their skepticism verbally. Video 2.3 shows shots of this training as well as the teachers' body language and some of their utterances.

»ε Video 2.3 Shots of the teacher training session

The classroom video showed that the guidance students received had in fact been minimal, focusing on assignment planning and finishing.

All in all, the test results did not show any significant differences between the conditions; the video data did however. We concluded that in spite of the small amount of guidance students received in the experimental condition, their performance was better on modeling due to the focus on the process and the use of models as tools for communication and orientation (Van Oers, 1988; Van Schaik et al. submitted a).

On the basis of our previous experiences we decided to design a new series of separate prototype lessons on designing. The only difference between the conditions was the way the lessons were enacted: in the control condition they were planned ahead, whereas in the experimental conditions the lessons were taught ad hoc or more or less 'on demand'. The student assignment remained the same.

Final experiment

Following the same time schedule as in the first experiment, we selected four schools (n=87) in the spring and explained our plans, again with the use of video. We did not organize any collective training sessions, nor any teacher trainer help, since the program for the schools was strict. However, it was the teachers that chose their own method of implementation. This meant that, apart from fitting the programme into their schedules, they had to find a way of implementing the prototype lessons and connect them to the practice workplaces. In two cases it was the teacher that was the connection: he taught both practice and the design lessons. In the other cases the prototype lessons were planned during mathematics periods. Schools were assigned to a condition in the same way as in the first experiment, and the implementation again took 8-10 weeks. The collected data was similar to that of the first experiment. The video observations differed in frequency since we had more schools to attend. We therefore focused on the crucial weeks in the process: the beginning, the period between weeks 3 and 6, and the end.

This experiment was analyzed in two studies: one was more quantitative, the other more qualitative in nature. From the quantitative study we found that, as in the first experiment, there was no difference in knowledge between the conditions as measured by the posttests (Van Schaik, Terwel, & Van Oers, submitted a). Two schools scored higher on the posttests; however the difference with other schools was not significant, while the schools were not in the same condition. We subsequently conducted a second study to analyze the actual differences in conditions and in processes between the four schools looking for an ex post-facto explanation for the different learning outcomes (Van Schaik et al., submitted b). From the analysis of the within-school enactment and across-school comparison it was clear that two schools differed from the other two in the way models were used in practice workplaces. At Schools 4 and 6 the models remained visible until the end of the process, whereas at Schools 3 and 5 the models seemed to disappear once the actual construction of the tandem tricycle had begun (see Video 2.4 for a comparison of presence of drawings in week 6). Moreover, at Schools 4 and 6 far more interaction on the models was found in the observations. Teachers and students used their models as tools for orientation and communication.

»ε Video 2.4 Presence of drawings in project week 6 at Schools 3 and 4

At the baseline level the video was one of the data sources that led to our conclusions in the separate studies. In other words, the baseline level described the findings from the video data. At the methodological and meta-levels we looked for the changes in the video and examined their correspondence with the methodological and theoretical changes.

The methodological level: adjustments to the intervention and method

Before we continue and discuss the way video informed the design process we need to explicitly describe the changes in the curriculum project and method

Table 2.1 Development of design and shifts in perspective informed by video

	Issues on Bbaseline level	Implications for **next** phase Methodological level: Intervention sublevel	Data sublevel	Shifts on Meta-level
Case study	- Knowledge remained situated - Models were provided - Client needs to be real - Integration subject matter*	- Guidance and instrument for teachers (with suggested lessons) - Prototype competition	- More distant video approach (more schools, more students) - Also quantitative data	Reflection on production process may lead to recontextualisation (prototype)
First experiment	- Drawings disappear during process - Models in experimental condition are better - Minimal guidance on theory and modelling* - Little or low quality student drawing*	- 'Prototype lessons' (explicit attention for models) - Backward engineering models	- Focus of observations around week 3-6	Models should be tools like professional designers
Final experiment				
a) First study	Better performing schools have: - Teachers with academic background - Higher teacher-student ratio		- Deeper qualitative analyses needed	'Disciplined perception' should be promoted (vocational & academic)
b) Second study	At best performing schools: - Explicit attention for disciplines - Models as tools the entire process	Parameters for assignment and teacher guidance: - Potential theory-rich assignment - Teacher student ratio - Teachers' background - Use modelling as core - Explicit reflection on disciplines		Integrated pedagogics with modelling as core activity.

* found in interviews or member checking

based on video information. The first column in Table 2.1 describes the issues that emerged after the first analysis of the video data.

The implications of the video analysis are shown in the second and third columns of Table 2.1. Divided over two sub-levels, both the adjustments of the intervention and the method are shown. For example, the second cell of the first row (Case study) describes how we redesigned the curriculum project for the first experiment. The theoretical shifts are displayed in the fourth column, to which we return in the next section.

The implications on the methodological level were results of the analysis at baseline level. Put differently, analysis at the first level led to adjustments at the next level. However, the adjustments became visible in the data after the fact. Only by reviewing the video of the whole project could the implications as planned after one stage be (re)viewed in the data of the next stage.

At the intervention sub-level, the main difference between the first experiment and the case study was that the assignment had been turned into a prototype contest. This was an attempt to acknowledge the problem of the situatedness of the knowledge involved, and the need for ecologically valid situations for the students. As a consequence, if was not enough for students to construct a working tricycle, they needed to have a production plan. In addition, a contest solved the problem of having 'real clients': the prototype jury panel was in fact the client. In order to stimulate the integration of subject matter into the project, an instrument was developed whereby possible references to mathematics and science, derived from the case study, were incorporated as examples. For example, for the teachers the instrument predicted that the students would most probably encounter the issue of how to propel the tandem tricycle. This provided an opportunity to bring in theoretical knowledge on transmission, about which an example lesson was provided. In addition, two teacher training sessions were organized, led by a teacher trainer who, in addition, was available for on-the- spot coaching.

The three-camera approach was maintained (see Figure 2.2 for a schematic overview and Video 2.5 for a panoramic video overview of the simulated workplace), with the hand held camera focusing on the possible modeling interactions of all students, according to a protocol based on the experiences in the case study. This resulted in video data that showed the practice process for the entire classroom rather than for a couple of subgroups in the case study. By way of example, in the case study the hand-held camera followed two subgroups in one observation, whereas in the first experiment the same camera switched back and forth between four subgroups. As a result it became clear what the routines in the workplace were. Again, students and teachers were interviewed during and after the project with the help of video data from earlier observations, although less frequently

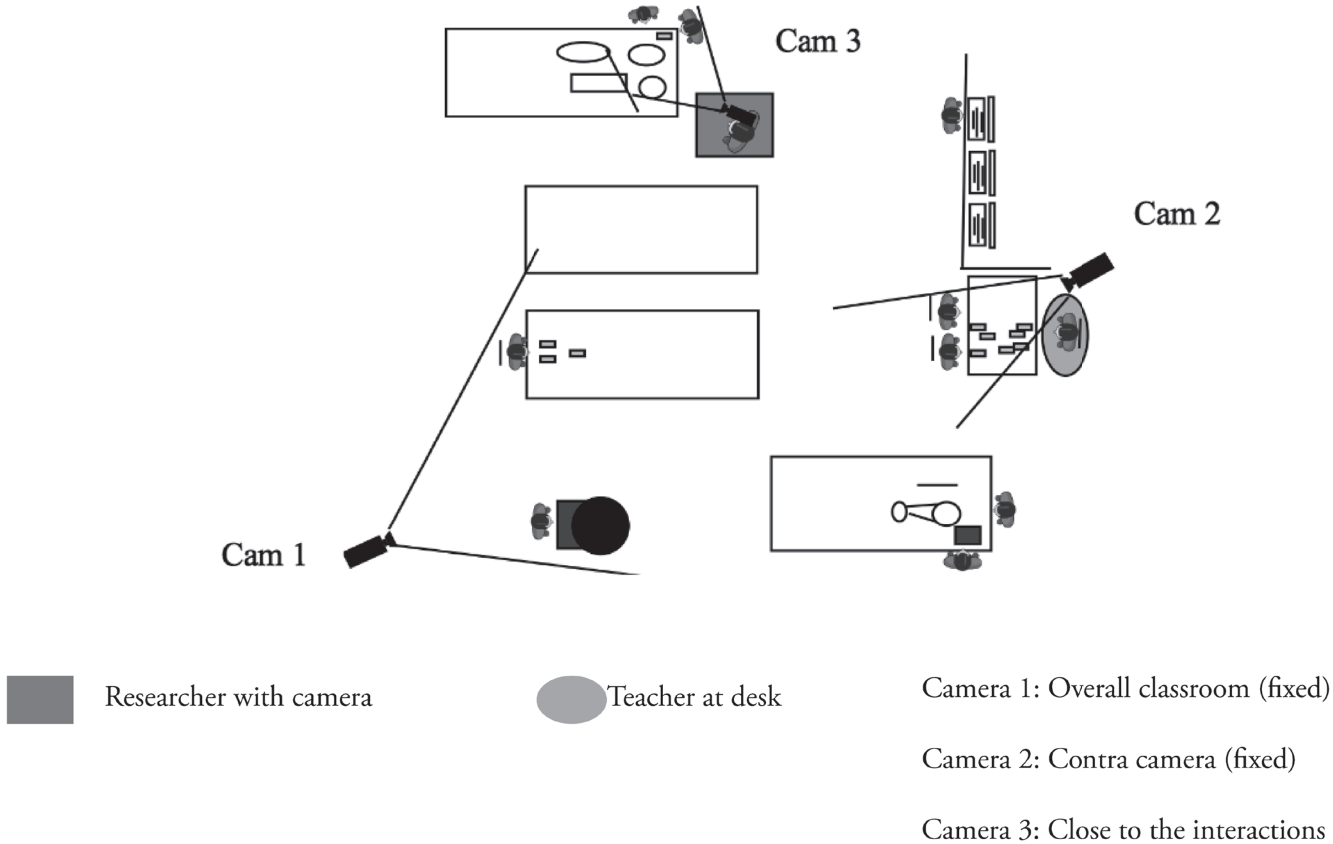

Figure 2.3 Video data collection in the classroom

than during the case study. The teacher training sessions were recorded as well. As in the case study, member checking was done afterwards.

»ε Video 2.5 Panoramic overview of simulated workplace

Compared to the first experiment only two significant adjustments were made to the second. First, the teacher guidelines of the first experiment were converted to a manual (Van Schaik et al. submitted a). Second, prototype lessons were developed and adapted for the two conditions. Both adjustments were intended to keep the students' drawings present during the entire process and to ensure moments for modeling guidance. A smaller adjustment to keep models present during the process involved the students' task to reverse engineer their products: the final prototype also needed to have a model on paper that resembled the actual construction.

In the second experiment the frequency of the video stimulated interviews per school was further reduced and only a single school training session organized. Earlier studies had taught us that the crucial moments in the students' design and construction process lay between weeks three and six. Since these were the weeks when the drawings tended to disappear the research focus shifted to the video observations.

After the first study of the second experiment we concluded that a qualitative analysis was needed to gain a better understanding of classroom processes. The quantitative data alone provided no clue to an explanation as to why there were only small, non-significant, differences. Subsequently we conducted a multiple case study, taking each of the schools involved as an individual case (Van Schaik et al. submitted b). With the conclusions of this study we would be able to close the cycle and return to the teachers with the implications for their practice.

The results from the video analysis at baseline level were the basis for the change in the intervention. In addition, the video was also used to provide information on the efficacy of our method. That is, it could show how students and teacher reacted to the more practical aspects of the assignment, as well as to the video cameras and the training sessions.

In the first case study, we observed not only that the tricycle students were very motivated, but also that other students who did not win the design contest were less motivated. We also found that the race game students lost their motivation a little due the teacher's role as client. As a result, the contest was continued as part of the next intervention, with the jury as real users: five-year old children, a school head teacher and a toy company.

The use of video cameras is intrusive to some students. Fortunately however,

Table 2.2 Hours of video data in the three phases

	video (hrs)	Schools	Students
Case study	30	1	6
First experiment	40	2	65
Final experiment	30	4	87

most students do not seem not to have any problem with it. At one point, early on in the project's case study, a student can be seen dancing and rapping in front of the camera. He asks the researcher: "Will I be on MTV?" The same student can be observed a few weeks later listening to the teacher in an interaction and apparently unaware of the camera, which was only a few metres away (see Video 2.6 for the two different reactions on the camera of one student). Although the cameras were obviously noticed, when the students were really involved in their tasks for the assignment they seemed to be forgotten. From this we learned to set up the cameras for the tests as well, to enable students to get used to it and reducing the amount of skylarking during the actual design and construction process.

»ε Video 2.6 Students' camera awareness

In addition, we noticed after a training session during the first experiment that some teachers showed a certain reluctance to accept that the intervention might work and thought that the project for students was too 'open' (see Video 2.3). In the next experiment we therefore created a more detailed lesson plan, tuned to the condition.

The major change in the intervention and method may be characterized by stating that we moved from close co-development with a few teachers to more distant cooperation with more teachers. From a single assignment, the intervention gradually developed into an almost ready-made lesson plan, while from a case study approach following two subgroups, the method became more integrated using both qualitative and quantitative data. The methodological approach developed into a broadspectrum methodology, with the video data as the interlevel and intralevel connections between the different data sources.

The meta-level: shifting perspectives

An examination of the video data over the three stages revealed that the actual curriculum project as well as our method changed as a result of our intervention adjustments. Furthermore, the classroom process changed. At the same time the video data itself shows how our perspective literally shifted; in the sense of capturing changes from a somewhat narrow experimental perspective on a few students in the case study, to a much wider perrspective on many students.

From these intervention adjustments (to the curriculum project and the method) we already notice a growing insight into modeling in knowledge-rich learning environment. In the case study the research was still exploratory, whereas in the final experiment the focus was narrowed down to how the models functioned as tools in the design process. For example, we knew that between project weeks 3 and 6 students' drawings might fade into the background. It would therefore be useful to carry out observations at that point in the project (e.g.Van Schaik et al. submitted b). It is interesting in this respect to note the amount of video data we collected over the three stages. During the case study we collected about 30 hours of video, while the number of hours during the first and final experiments amounted to 40 hours and 25 hours respectively (see Table 2.2). The overall data included classroom observations, interviews and teacher sessions.

The amount of video data per school dropped form 30 hours to 20 hours, and eventually to less then 10 hours. The explanation for this is twofold. First, during observations our knowledge of what to shoot improved as our understanding of classroom and modeling processes improved. Second, as the research progressed the timing of our observations improved. Both explanations imply a shift in perspective.

A more abstract, less practical and observable shift took place in the evolution of the subsequent research questions and hypotheses for each study. A characteristic of design research is that it is "pragmatic as well as theoretical in orientation in that the study of function – both of the design and of the resulting ecology of learning – is at the heart of the methodology" (Cobb et al., 2003, p. 9). After our discussion of the pragmatic part, the question remains as to whether the theoretical shifts are also visible in the video data.

The last column of table 2.1 displays the shifts in our focus at the meta-level as derived from the video data. The theoretical development are best illustrated by the shifts in our research questions for each study. The research questios for each stage and study were:

For the case study: *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 modeling?*

For the first experiment*: Do students in the experimental condition acquire more knowledge and better understanding in mathematics and science?;*

Do students in the experimental condition develop a better understanding of the use of models?; and

Do students in the experimental condition produce better models/drawings of their own products?

For the final experiment:

Study A: *By designing a real product themselves, do students,guided in a co-constructive way, gain codified knowledge in mathematics and science and a better understanding of modelling?*

Study B: *What was the actual teaching/learning practice in the schools and how did the schools differ, especially in how the models functioned as tools in the design process?*
Was the teaching/learning practice aimed at designing and understanding related to the disciplines, both the academic and the vocational?

The shift from a more open, exploratory question to a more narrowed down question could ultimately be interpreted as an indication of development at the theoretical level. Although the questions in themselves do not reveal what exactly was learned from the video data, they do reveal a shift in perspective. Initially the focus is on the learning environment, the models and the teaching/learning practice. Next, the output comes into focus as well of course as the differences between the conditions. Finally, the teaching/learning process is made explicit (guidedco-construction) and the questions concern the functioning of the models as tools. These shifts are in line with the pragmatic shift at the intervention and method sublevels. For example, the assignment client was changed during the intervention to a prototype contest, justifying us to ask students to create final drawings. These were, in turn, our output measures. Prototype lessons were also developed, creating moments for teachers to instruct the students in using models as tools in other contexts. At the same time, at the method sublevel, output measures were incorporated into, and integrated with, the video analysis.

Additional theory was required, especially for the intervention adjustments. The work of Lave and Wenger (2005) was used to create the prototype contest, using their idea to the effect that (collective) reflection on the production process promotes learning in a community. Moreover, MacDonalds and Gustafson (2004) helped us understand the way models can function as tools in a design process and thus the need for a final drawing. Finally, the concept of disciplined perception (Stevens and Hall, 1998) constituted a new framework for understanding how teaching could enhance students' understanding and codified knowledge: how teachers could guide students in adapting the ways of examining and interpreting that are common to the disciplines (vocational and academic).

Not only did we learn when to look for what in a practical way, we also gained a deeper understanding of what we needed to know when collecting and analyzing video data. In short, video makes changes of perspective and insights visible over time.

From data to evidence at multiple levels

The main point of this study is to show how video data can guide a research project. Design research is developmental and emergent, that is, it designs and redesigns programs and interventions collaboratively with participants on the basis of outcomes and incidents that occur during the process. As a consequence, the data collected at each stage not only include information that serves to examine the effectiveness of the intervention, but also information that necessitates analysis at other levels. It follows that video is an indispensable data source. Without it we would not have 'seen' how teachers provided ready-made models, or how drawings gradually disappeared at the workplaces, or how the curriculum project was actually enacted.

In these pages we aimed to explain how our video data guide our academic enterprise at three levels.

For each level we provided answers to the following questions:
a. What was the value of the video data in this design research?
b. To which adjustments did the video data lead?
c. How were these changes visible in the video data?

From the baseline level, the video data helped us redesign the curriculum project and the method. As a result the analysis of video observations and interviews led to a number of adjustments at the methodological level. First of all the observation video data showed us how the interventions worked in the classrooms. Second, the video data helped us triangulate our findings with the participants, thus enabling us to refine our analysis. Finally, the video observations helped our training procedures and our planning layouts for participating schools. Restricting our range to quantitative data would have resulted in fewer insights into the school processes and a less implementable curriculum project in the two experiments. Moreover, some processes would have remained permanently hidden (e.g., disappearing drawings, types of teacher guidance) if our experimental analyses had been based solely on the test results. More specifically, the video data show that teacher-provided models tended to disappear during the construction process, and that teachers in the guided co-construction condition stressed the use of student drawings. Although the issues on which the adjustments were based were directly visible in the data, the adjustments that were actually carried out could be reviewed only after the redesigned intervention had been reimplemented. The present analysis as such is a triangulation of our design process after the fact, which would also have been impossible without the video data.

With hindsight we see that the extensive use of video data co-determined the course of the research trajectory in ways that would not have been possible with quantitative data alone. On the basis of the quantitative data we would have concluded that the project's research conditions (providing codified knowledge versus co-constructing) had not worked out as predicted in the context of knowledge-rich environments. On the basis of our workplace observations we were able to refine the design's guiding principles and conduct a replication study, which, as it happened, yielded basically the same answers to our main research questions. Further, the video data from students' and teachers' workplace activities enabled us to discover in the redesigned project that the design and use of the models differed for the various schools in. The data even enabled us to speculate about conditions that might be conducive to such situations. As a result, our attempts to find answers to our original research questions concerning the learning of codified knowledge in simulated knowledge-rich vocational education workplaces obviously needed theoretical refinements that no longer focused on determining the value of broadly defined conditions such as 'guided co-construction', but concentrated on actual microgenetic learning trajectories in the use of modelling (as a tool for orientation and communication) and the way this process was guided by discussions and appropriately tuned-in instructions by an expert (teacher). It is our contention that a decade of studies on the issue of providing versus co-construction has reached a new stage with detailed video-analysis. Such studies should in our view be defined as studies of providing in the context of guided co-construction and as studies of the ways co-construction may support the meaningful use of tools and codified knowledge in students' problem solving when engaged in processes of construction and design.

In addition, the video data functioned not only as our source for analysis or as a tool for interviews and participant member checking, it also brought the intermediate concepts and solutions (Engeström, 2009) back to the schools. For example, when we showed the observation videos to the teachers, one of the effects was that the video data informed the teachers of their own practice and our perspective on it. If design-based research is to improve theory and practice, and if it is to be regarded as an open, non-linear process with acknowledgement of the participants' agency, then relaying the insights to the workshop should be a part of the research. The Vygotskian notion of double stimulation (Engeström, 2009) could thus be extended to triple stimulation: The first stimulus in the formative intervention would constitute the problem, the second stimulus the tool (intervention program) as adapted by the participants, the third the intermediate concepts and solutions brought back to the participants. The cycle would thus be closed and, by way of a next step, a new problem might be formulated and research continued.

We believe to have demonstrated that video is not just a rich data source. We also believe it to be indispensable in design research if our aim is to improve theory and practice and, in addition, to reflect on the method itself. Especially if we regard design research as open-ended and value the agency of participants.