4 The Interconnected Model of Teacher Professional Growth as a means to assess the development of a mathematics teacher

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Abstract
In this qualitative study we used a case study approach to observe and analyse a mathematics teacher who was challenged to redesign her lessons during network meetings with colleagues. Changes in practical knowledge are described by means of concept maps and semi-structured interviews. We applied cycles of change from the Interconnected Model of Teacher Professional Growth to describe the teacher’s professional development. We show that the teacher’s pedagogical content knowledge changes in the domain of practical knowledge, and that controlled experimentation and reflection are necessary conditions to learn a new teaching strategy and to develop a series of lessons for pupils.

Keywords
Professional development, practical knowledge, teaching practice, modelling teacher change

4.1 Introduction
Recent developments of the mathematics curriculum in Dutch secondary schools and more attention to inquiry-based teaching in (statistics) education have made it increasingly important for teachers to be able to redesign their teaching practices. This development aligns with similar changes in other countries. According to Sowder (2007, p.157) several U.S. surveys reported that “improving the quality of teaching is the most important way to improve public education”. Much of what teachers need to learn must be learned in and from practice (Hammerness, Darling-Hammond & Bransford, 2005), and well-designed professional learning helps teachers to address changes needed in teaching and learning (Darling-Hammond, Chung Wei, Andree, Richardson & Orphanos, 2009).
Past research (see Guskey, 1986; Fullan & Stiegelbauer, 1991; Clarke & Hollingsworth, 2002) has shown that, in order to be effective, teacher learning programmes should be active and practice-oriented (Clarke & Hollingsworth, 2002), and meaningfully situated in teachers’ classrooms (Putnam & Borko, 2000). The experience of implementing new teaching practices
changes teachers’ knowledge and skills when they experience that these yield better learning results and lead to pupils’ appreciation (Guskey, 1986, 2002). Reflection on the personal activities in the classroom can be considered as essential for teacher change. From the above it follows that we will take teachers’ educational practice as a starting point for their development.

This study focuses on the continuous and long-lasting professional development of mathematics teachers. We have chosen to use a strategy in which teachers collaborate in a network of colleagues, where the network meetings act as a sounding board (see Stiles, Mundry, Loucks-Horsley, Hewson & Love, 2009). In network meetings they further improve and evaluate an earlier developed and implemented teaching design in the field of statistics for 7th grade pupils. The focus of this teaching design is on inquiry-based student work, aimed at students designing, performing and reporting statistical research. Through the network meetings teachers are introduced to the pedagogy of inquiry-based teaching. Our hypothesis is that the discussing of teachers’ experiences in the network meetings, their design of the lessons and their reflections lead to their development of practical knowledge (see also Darling-Hammond & McLaughlin, 1995; Meijer, 1999; Verloop, Van Driel & Meijer, 2001). We will use the Interconnected Model of Teacher Professional Growth by Clarke and Hollingsworth (2002) as a means to describe the process of professional development (see also De Jong, Van Driel & Verloop, 2005; Anderson & Moore, 2006) and study teacher change.

4.2 Theoretical framework

4.2.1 Teacher’s knowledge

In literature, teacher change and professional development are connected in a way that professional development aims at establishing a change in teacher’s professional activity. Clarke and Hollingsworth (2002) describe several perspectives on teacher change and they suggest that the central focus of current professional development efforts most closely aligns with the ‘change as growth of learning’ perspective. They mention (ibid., p.948): “Within this perspective, change is identified with learning, and it is regarded as a natural and expected component of the professional activity of teachers and schools”. They hereby disassociate their perspective on professional development activities from the historical perspective, where
‘one-shot’ workshops aimed at teachers mastering prescribed knowledge and skills. These ‘one shot’ approaches have been described as ineffective to change teachers’ knowledge and classroom practices (see also Guskey, 1986; Wood & Thomson, 1980; Fullan & Stiegelbauer, 1991). According to the ‘normative-reeducative strategies’ (Chin & Benne, 1969) teacher change must take place as a result of reflection on the teaching practice, in which consultation with colleagues is an important element (see also Meijer, 1999; Gallagher, Goudvis & Pierson, 1988). These changes take place on the teacher’s own initiative, which is an important difference with the (‘one-shot’) strategies in which changes are imposed by school boards or policy makers.

In this study we investigate changes in teachers’ practical knowledge, as changes in practical knowledge are necessary for changes in teachers’ behavior (Ajzen, 1985). Researchers have indicated that teachers’ beliefs, attitudes, and practical knowledge are crucial factors in promoting educational reforms, such as the implementation of inquiry-based instruction (Choi & Ramsy, 2010). In literature (Elbaz, 1981; Fenstermacher, 1994; Pajares 1992; Black & Halliwell, 2000; Verloop, Van Driel & Meijer, 2001; Meijer, Verloop & Beijaard, 1999, Pintó, 2005) the term practical knowledge is frequently used for the purpose of studying teachers’ knowledge that support and guide their practice. Fenstermacher (1994) defines practical knowledge as ‘the knowledge teachers themselves generate as a result of their experiences as teachers and their reflections on these experiences’. Verloop et al. (2001) add that (p.446): ‘(...) in the mind of the teacher, components of knowledge, beliefs, conceptions, and intuitions are inextricably intertwined’. Pajares (1992) states that knowledge and beliefs are seen as inseparable, although beliefs are seen roughly as referring to personal values, attitudes, and ideologies, and knowledge to a teacher’s more factual propositions (see also Meijer, Verloop, & Beijaard, 1999). Teachers’ practical knowledge is conceptualized as action-oriented and person-bound. According to Elbaz (1981) teachers are actively reflecting on their actions and, accordingly, constructing their own theories. As it is constructed by teachers in the context of their work, practical knowledge integrates experiential knowledge, formal knowledge, and personal beliefs (Verloop et al., 2001). People's beliefs have a predictable influence on their attitudes, thus, people construct their attitudes on the basis of their beliefs (Albarracín & Wyer, 2005). Meijer, Verloop and Beijaard (1999, p.60) mention that teachers’ practical knowledge is mainly tacit, which indicates that teachers are often not used to articulating their knowledge. It appears that it is difficult to distinguish between teachers’ knowledge and beliefs on one hand and between teachers’ beliefs and attitudes on
the other hand (Jones & Carter, 2007). Therefore, in this study we use the term practical knowledge to designate teachers’ knowledge, beliefs and attitudes.

Shulman (1986a, p. 9-10) states that teachers’ practical knowledge, with special emphasis on content, concerns three categories. These are:

1. Subject matter content knowledge. This is the subject knowledge that is required in order to be able to teach the subject in question (Sowder, 2007).

2. Pedagogical content knowledge (PCK): ‘(...) It includes the ways of representing and formulating the subject that make it comprehensible to others’ (Shulman, 1986a, p.9; see also Shulman, 1986b). PCK means that teachers understand why pupils find certain concepts particularly difficult or easy.

3. Curricular knowledge: This ‘is represented by the full range of programs designed for the teaching of particular subjects and topics at, a given level, the variety of instructional materials available in relation to those programs, and the set of characteristics that serve as both the indications and contraindications for the use of particular curriculum or program materials in particular circumstances’ (Shulman, 1986a, p.10).

Grossman (1990) added:

4. Knowledge of context: Knowledge of context includes knowledge of school setting, for example culture, and knowledge of individual students (Magnusson, Krajcik & Borko, 1999; Van Dijk & Kattmann, 2007).

For this study, it is relevant to emphasize that in the subject of statistics objectives have recently shifted from statistical knowledge and skills towards statistical reasoning or statistical literacy, for example, in the Netherlands and in the US (see Burrill, 1991; NCTM, 1989, 1991, 2000; De Lange, 1987). The goals of ‘Data analysis and probability’ in the curriculum include: ‘Enable all students to formulate questions that can be addressed with data and collect, organize, and display relevant data to answer them’ and ‘Select and use appropriate statistical methods to analyze data’ (see NCTM standards, 2000). Statistical literacy is seldom achieved by following the textbook (Doerr & English, 2003; Chance, 2002), but requires organizing inquiry-based student activities. Inquiry-based teaching (see National Research Council, 1996) is a pedagogical approach that invites students to explore content by posing, investigating, and answering questions.

In the context of the innovation of the Dutch statistics curriculum mathematics teachers should acquire novel PCK and curricular knowledge, and possibly subject matter content knowledge.
4.2.2 Teachers’ professional development

In this study the Interconnected Model of Teacher Professional Growth (Clarke & Hollingsworth, 2002), as shown in Figure 4.1, is used to represent chains of events that are responsible for changes in teachers’ practical knowledge. The Interconnected Model of Teacher Professional Growth (ICMTPG) suggests that teacher change occurs in recurring cycles through the mediating processes of ‘reflection’ and ‘enaction’ in four distinct domains that encompass the teacher’s world (Clarke & Hollingsworth, 2002). In short, experiences in the classroom, which are directed from the external domain or from teacher’s practical knowledge, lead to salient outcomes which influence teacher’s practical knowledge. Reflection is the ability to look back on an experience in a structured manner and to draw conclusions for future actions (Korthagen & Vasalos, 2009). Enaction is not only ‘action’, but more strongly, each action represents a confirmation of something a teacher knows, believes or has experienced (Clarke & Hollingsworth, 2002).

Figure 4.1: The Interconnected Model of Teacher Professional Growth

The ICMTPG is non-linear and it recognizes the complexity of professional growth through the identification of multiple growth pathways between the domains. It recognizes professional growth as an inevitable and continuing process of learning (Clarke &
Hollingsworth, 2002). Change in one domain is translated into change in another domain through the mediating processes of reflection (dotted arrows) and enaction (solid arrow). We will describe the different domains of the ICMTPG (see Figure 4.1) below and how we use this framework in this study. This will be elaborated further in section 4.3.4.

4.2.2.1 External source of information or stimulus in the external domain
The external domain is distinguished from the other domains by its location outside the teacher’s personal world. Clarke and Hollingsworth (2002) mention that professional publications and conversations with colleagues are both important external sources of new information and stimulus. The external domain can be interpreted as the initiator of professional development. In our study, the network meetings serve to exchange knowledge and experiences, which will often trigger reflection on each other’s teaching practice and ideas. This may in turn result in an expansion of practical knowledge and refining one’s own teaching (Darling-Hammond et al., 2009; Borko, Mayfield, Marion, Flexer & Cumbo, 1997). Knapp (2004) and Day (1999) state that networks are powerful learning environments for teachers. According to Knapp (2004, p.121): ‘(...) The effort of collective sense making often prompts teachers to listen to children differently, examine their own practice more closely and reimagine possibilities for their work’. In our study, the role of the researcher is to manage the network meetings and to guide the teachers towards an inquiry-based teaching design.

4.2.2.2 Professional experimentation in the domain of practice
The key ingredient of this domain is teachers experimenting in their classrooms. Practices that are found to work - that is, those that teachers find useful in helping students attain desired learning outcomes - are retained and repeated. Those that do not work or yield no tangible evidence of success are generally abandoned (Guskey, 2002, p.384). In this study, experimenting is initiated by the network and guided by teacher’s practical knowledge.

4.2.2.3 Salient outcomes in the domain of consequence
Change in the domain of consequence is firmly tied to the teacher’s existing value system and to the inferences the teacher draws from the practices of the classroom. Clarke and Hollingsworth (2002) mention as an example that using a new teaching strategy can have a positive outcome for one teacher, but a feeling of loss of control for another teacher. This domain is therefore coloured by teacher’s expectations. Parallel to Guskey’s model of teacher
change (2002) significant change in teachers’ practical knowledge occurs primarily after they gain evidence of improvements in student learning. Teachers value a teaching strategy, because they have seen it works and that experience shapes their practical knowledge. In this study this domain is deepened by discussions during the network meetings, in which teachers reflect on their classroom experiences and the teaching design.

**4.2.2.4 Knowledge, beliefs and attitudes in the personal domain**
The personal domain reflects teachers’ practical knowledge, which encompasses teachers’ knowledge, beliefs and attitudes. A more detailed description of ‘practical knowledge’ is found in section 4.2.1. This personal domain may be considered as the resultant of the previous three domains.

**4.3 Context of the study and research questions**

**4.3.1 Research questions**
This study aims to identify the events that contribute to the development of practical knowledge of one mathematics teacher, Annet. She improves an earlier developed teaching design in the field of statistics collaboratively in a network of colleagues. Annet was involved in setting-up and implementing the first design and the revision and implementation of the second design one year later. Therefore, Annet’s development can be addressed as long-term. The first research question focuses on Annet’s practical knowledge and is formulated as:

*Which long-term development in practical knowledge of Annet can we describe as a result of working in a teacher network, collaborating on a design and implementation of a series of lessons for teaching statistical research skills?*

As said, we will use the reflection model of Clarke and Hollingsworth (2002) with the objective to describe the process of professional development. Annet’s teaching practice forms the starting point for this development. The second research question in this study focuses on the ICMTPG. The second research question is:

*To what extent are the cycles of change, derived from the ICMTPG, adequate in describing the change of Annet’s practical knowledge?*
4.3.2 The professional development program

The professional development program in school year 2007-2008 consisted of further improving, implementing and evaluating a statistics project for 7th-grade pupils. In chronological order, the pupils conducted the following activities, spread over nine lessons:

1. The teacher presented an introductory assignment for ordering ski-shoes. Pupils determined the different shoe sizes and their distribution.
2. Pupils came up with a self-initiated research question in which distribution aspects come up, similar to the introductory assignment.
3. Pupils collected their own data, analysed the data and computed measures of centre. A typical data collection method for pupils were developing and administering a questionnaire,
4. Eventually, pupils made a poster of their research project with diagrams of the data, and presented their poster to their peers. Pupils commented upon each other’s research outcomes.

Pupil’s activities mentioned above required the following knowledge of teachers:

1. Subject matter content knowledge: Teachers needed subject knowledge in the domain of statistics, for example knowledge of (the use of) measures of centre, (the ways) to collect data and represent data.
2. Pedagogical content knowledge: We assumed that, of the four knowledge bases, PCK has the greatest impact on teachers’ classroom actions (see also Gess-Newsome, 1999). Teachers had to:
   - Judge the prior knowledge of the pupils: what do my pupils already know about statistics?
   - Judge the adequacy of the assignments: which assignments offer the best learning outcomes for my pupils?
   - Select the most appropriate teaching strategies: which method is suitable for my pupils?
   - Select the optimal guidance for the pupils: which role do I have in guiding my pupils with this type of assignments? How do I monitor the process?
   - Consider how to assess these assignments.
3. Curricular knowledge: The teachers should be aware of the intended learning outcomes in statistics education and the steps pupils had to make to reach these outcomes.

4. Knowledge of context: The classroom practice of the teachers was part of the school environment and therefore depends on school rules. Besides that, the teachers had to take into account the differences between students and students’ backgrounds.

The teacher’s task was to guide pupils during their research activities and statistical analysis of the data they collected. These activities were new to the pupils as well as to the teachers. Since traditional mathematics lessons are based on mathematics textbooks, this was a completely different way of teaching and learning mathematics. The role of the teacher in an inquiry-based classroom is quite different from a teacher in a traditional classroom. Instead of providing direct instruction to students, teachers help students generate their own questions and guide their investigations (see Keys & Bryan, 2001).

The professional development program started in school year 2006-2007 (round 1) and continued in school year 2007-2008 (round 2). In both years at least three teachers participated. Annet was the only mathematics teacher who joined the network both school years. Therefore, she is an interesting teacher for describing the long-term process of teacher change.

The professional development was organised by letting teachers design their lessons in a network with colleagues facilitated by a teacher trainer, who is the first author of this paper. The network meetings were used to discuss the design and reflect on the lessons taught by the teachers. We hypothesize that Annet’s practical knowledge would develop during the network meetings and the lessons, and this development will be outlined by means of concept maps and semi-structured interviews. Lesson observations are conducted to indicate teacher behaviour during the implementation of the teaching design.

4.3.3 Network meetings
During the network meetings the teachers further improved the teaching design for 7th grade pupils, in the field of statistics, in which pupils conduct research under a teacher’s supervision. Of course Annet, due to her participation in the former year, already became more acquainted with developing and teaching research assignments.
The following conditions for teacher networks aimed at contributing to teacher change (see Day, 1999; McDonald & Klein, 2003):

1. Teachers are enabled to exchange experiences and knowledge about their teaching,
2. The network meetings have a clear focus and purpose,
3. The teachers meet regularly in the network setting,
4. The issues addressed are linked to the everyday practice of the teachers involved.

The teacher network in this research study met these conditions and it can therefore be expected to function as a powerful learning environment for the teachers. The design of the network meetings and the way the mentioned conditions fit into this design are discussed in this section.

We identified the following aims of the network meetings:

1. To introduce teachers to the pedagogy of inquiry-based teaching. The supervisor familiarized the teachers with this teaching method by providing relevant literature.
2. To learn to recognize which characteristics of the teaching design impedes or improves its implementation or effectiveness.
3. To learn to focus on feasible teaching goals. These goals are related to two specific domains, namely statistics and research skills.
4. To learn to focus on feasible personal development goals. These personal development goals could vary from learning to supervise pupil group work effectively to a reintroduction to the field of statistics.
5. To get acquainted with the various opinions of colleagues. The teachers had to achieve agreement on the contents and the implementation of the teaching design. This aim differs from the previous aims, because this is a network goal. The former goals are aimed at improving the practical knowledge of the teachers.

Each network meeting lasted 50 to 90 minutes. During the first network meeting, the teachers agreed on a minimum of five network meetings, which they thought were necessary to improve and evaluate the teaching design. Roughly, it can be said that in the first four network meetings the teachers together determined the renewed structure and implementation method of the teaching design. The supervisor organized the meetings, provided information, stimulated the progress of the work and stimulated reflection. This is a matter of collaborative learning; the researcher abdicates her authority and empowers the small group who is given a
more or less open-ended, complex task (see Rockwood, 1995a, 1995b). The fifth meeting was an evaluation meeting and took place after the teaching design had been implemented.

Figure 4.2 presents the intervention, including the network meetings and lessons, specified for Annet. The intervention in this study includes the whole of network meetings and lessons.

N\textsubscript{x} = Network meeting number x; L\textsubscript{x} = Lesson number x.

### 4.3.4 An operationalization of the Interconnected Model of Teacher Professional Growth

In the former sections we described the four distinct domains which encompass the teacher’s world according to the ICMTPG (Clarke and Hollingsworth, 2002). Figure 4.3 represents an operationalization of this model, adjusted to this research study. The numbered arrows will be explained in section 4.6.2.
We will describe the different domains of the ICMTPG (see Figure 4.3) below.

**External source of information or stimulus in the external domain**

We will refer to this domain as ‘Network of mathematics teachers’. In our study the conversations with colleagues in the network is an important stimulus. During the network meetings the teachers were enabled to exchange experiences and knowledge about their teaching. Another stimulus for the teachers is the supervisor, who, for example, shared literature with the teachers. However, the supervisor did not directly influence the creation of the teaching design.

**Professional experimentation in the domain of practice**

During the network meetings teachers agreed on improvements concerning pedagogical and teaching goals (see section 4.3.3). The domain of practice in this study represents ‘Teacher’s classroom practice’, in particular the implementation of the improved teaching design and teachers’ behavior during the lessons.

**Salient outcomes in the domain of consequence**

In our research study, salient outcomes are new conclusions drawn by the teachers with respect to their classroom practice, named ‘Teacher draws new Conclusions’. The salient outcomes describe the reflection of the teachers on what happened during the lessons and, for the teachers, the important events during the lessons.

**Knowledge, beliefs and attitudes in the personal domain**

We refer to this domain as ‘Practical knowledge’. As we mentioned in section 4.2.1, we use the term practical knowledge to designate teachers’ knowledge, beliefs and attitudes.

The arrows in the model, as shown in Figure 4.3, are elaborated for this research in tables 4.1 (reflection) and 4.2 (enaction). It is shown how the different forms of reflection and enaction occur in our intervention with network meetings and lessons.
### Table 4.1: Reflection from one domain to another in the Interconnected Model of Teacher Professional Growth

<table>
<thead>
<tr>
<th>FROM</th>
<th>[PK]</th>
<th>[NoMT]</th>
<th>[TCP]</th>
<th>[TdnC]</th>
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<tbody>
<tr>
<td>[PK]</td>
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<tr>
<td>[NoMT]</td>
<td>Reflection on what happened during the network meetings can give rise to a change in practical knowledge.</td>
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<tr>
<td>[TCP]</td>
<td>Reflection on teachers’ classroom practice can give rise to a change in practical knowledge.</td>
<td>—</td>
<td>—</td>
<td>Reflection on teachers’ classroom practice will determine what happens in the classroom.</td>
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<tr>
<td>[TdnC]</td>
<td>Reflection on how teachers perceive their classroom practice can give rise to a change in practical knowledge.</td>
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</tbody>
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PK = Practical Knowledge, NoMT = Network of Mathematics Teachers, TCP = Teachers’ Classroom Practice and TdnC = Teacher draws new Conclusions. ‘—’ means that there is no direct reflection from one domain to another.
Table 4.2: Enaction from one domain to another in the Interconnected Model of Teacher Professional Growth

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<th>FROM</th>
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<th>NoMT</th>
<th>TCP</th>
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<tr>
<td>[PK]</td>
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<td>Teachers’ practical knowledge</td>
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<td>The network meetings</td>
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<td>determined pedagogical</td>
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<td>approach and content of the</td>
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<td>teaching design.</td>
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<tr>
<td>[TCP]</td>
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<td>—</td>
<td>—</td>
<td>What happened in the classroom,</td>
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<td>the reaction of the pupils,</td>
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<td>of the teaching design.</td>
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<td>[TdnC]</td>
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</tbody>
</table>

PK = Practical Knowledge, NoMT = Network of Mathematics Teachers, TCP = Teachers’ Classroom Practice and TdnC = Teacher draws new Conclusions. ‘—’ means that there is no direct enaction from one domain to another.

A closer look at tables 4.1 and 4.2 shows that reflection mainly occurs to the domains ‘Practical knowledge’ and ‘Teacher draws new conclusions’ and that enaction mainly occurs to the domains ‘Network of mathematics teachers’ and ‘Teacher’s classroom practice’.

4.3.5 Changes of Annet during the former school year

In a former qualitative study (Witterholt, Goedhart & Suhre, submitted) we discussed the initial development of Annet. From the data, we identified three categories in which changes in practical knowledge of Annet occurred, namely ‘Selection of learning material’, ‘Providing feedback to pupils’ and ‘Group assignment’. The categories are all connected to Shulman’s categories (1986a), mainly to pedagogical content knowledge. The most important changes originated from the implementation of the teaching design. Examples are the ideas about the introductory assignment, which did not relate enough to pupils’ prior knowledge, the difficulties with pupils working in groups and the lack of experience Annet had with supervising pupils while they were carrying out research tasks. We found that changes in
practical knowledge originate from alignment or lack of alignment of expectations expressed during the network meetings and experiences during the implementation of the teaching design, resulting in reflection on the classroom activities during the evaluation network meetings (Witterholt et al., submitted).

4.4 Method

4.4.1 Participants

The network in this study comprised three mathematics teachers from the same school in presence of a supervisor who is also the researcher. The teachers voluntarily signed up for participation in this study during a meeting attended by all mathematics teachers working at the school as well as the researcher. In this paper, we will focus on one mathematics teacher, Annet. This is a fictitious name. Below, important information about Annet is given.

| Sex: Female |
| Age: 49 |
| Number of years of experience in education: 11 |
| Number of years of experience in teaching in the first stage of secondary school: 4 |
| Experience in statistical research assignments: Assisted in one project in the third year of ‘mavo’ (junior general secondary education). Furthermore, she participated in the network meetings for the development, implementation and evaluation of a teaching design for 7th-grade pupils in the field of statistics in 2006-2007. |
| Experience in collaborating with other mathematics teachers: Tailoring levels and skills of pupils, tests and study guides. Finally, the realization of a teaching design for 7th-grade pupils. |
| Experience in statistics: At University – subject knowledge, except for school statistics, has largely been forgotten. |

The pupils were 7th graders, the first year of Dutch secondary education, aged 12-13 years. Both the teachers and the pupils had little or no experience with this type of teaching. The school is a large comprehensive school with ‘vmbo’ (pre-vocational secondary education), ‘havo’ (senior general secondary education) and ‘vwo’ (pre-university education).
sections in a small town in the north of the Netherlands, with pupils mainly from villages around the town.

4.4.2 Research instruments
Four different research instruments were used in order to provide an extensive overview of teacher’s practical knowledge and its changes. These research instruments included concept maps, semi-structured interviews, registrations of network meetings and lesson observations. Below, each instrument will be briefly discussed.

4.4.2.1 Concept maps
Annet drew up a number of concept maps – a pre-concept map CM[0] before the first intervention and a post-concept map CM[1] afterwards in the school year 2006-2007, and a third measurement, CM[2] after the intervention in the school year 2007-2008. The central theme in all concept maps was ‘learning and teaching statistical research skills’. After having drawn up the concept maps were individually discussed with Annet. The concept map discussions took about 30 to 40 minutes. The discussions were taped with a voice recorder and transcribed afterwards. Figure 4.2 reports the dates of the drawing up of the concept maps of Annet and the subsequent discussions.

4.4.2.2 Interviews
Individual semi-structured interviews were held directly after the concept map discussions. The interviews were taped with a voice recorder and transcribed verbatim afterwards. In accordance with the naming of the concept maps, we will call the pre-interviews Int[0], Int[1] and Int[2]. All interviews contained exactly the same questions. The interviews supplemented the concept map discussion to make sure no information was excluded. For example, the teachers were asked how they felt that pupils should learn statistical research skills and how these skills should be taught. The semi-structured interview took about 15 to 20 minutes per teacher.

4.4.2.3 Registrations of network meetings
All five network meetings were taped with a voice recorder and subsequently transcribed. The transcriptions provided insight into:
1. Annet’s practical knowledge and, particularly, changes in her practical knowledge.
2. Reasons why Annet and the other teachers revised their practical knowledge.
3. Whether the network meetings functioned as a powerful learning environment for the teachers.
4. The changes to the teaching design which were discussed during network meetings. The teaching design in itself is left out of consideration in this part of the study.
5. Teacher’s experiences with the implementation of the design.

**4.4.2.4 Lesson observations**

A total of six lessons were planned to teach the design. Two of these lessons, the first and the fourth lesson, were recorded with a video camera, focusing in particular on Annet’s activities during the lesson. Everything she said was subsequently transcribed. These transcriptions aimed to find out what Annet said during the network meetings matched with her actions in the classroom.

**4.4.3. Data analysis**

The concept maps and the associated interviews provided insight into the teacher’s practical knowledge and into the relationships that exist between the knowledge and concepts indicated by the teacher (see also Zwart, Wubbels, Bergen & Bolhuis, 2007; Meijer et al., 2002). The concept maps and interviews enabled Annet to indicate her knowledge in the fields of statistics, statistics teaching and the supervision of research assignments. Differences between concept maps and the associated interviews at different moments enabled us to check whether any development has taken place in Annet’s practical knowledge, whether goals have been revised and whether expected bottlenecks have indeed occurred. Transcriptions of network meetings, concepts maps and interviews gave us insight into teacher’s expectations according to further improving and implementing the teaching design.

Data analysis took place in a number of phases. Although the analysis took place for all participants, we only focus on the data of Annet.

*Phase 1: Analysis of concept maps and interviews.* All three concept maps of Annet were analysed and compared for themes and concepts. Shulman’s (1986a) classification (see section 4.2.1) was used as the basis for categorizing themes and concepts. Differences and similarities were subsequently described and the transcribed texts of the concept map discussions and the interviews were also compared. Recurring as well as newly brought up themes and concepts were identified.
Phase 2: Analysis of network meetings and lessons. Transcriptions of teachers’ consultations were analysed on recurring and newly brought up themes per network meeting. The video recordings of lesson 1 and lesson 4 were watched and Annet’s actions and utterances during the lessons were transcribed. Data from network meetings and lessons were combined in order to check whether the teacher’s actions matched the agreements made during the network meetings.

Phase 3: Combining data from the various research instruments. Data triangulation was used to guarantee the validity of this qualitative study (see also Meijer et al., 2002 and Denzin, 1970). To this end, the data from the four research instruments were combined. We examined whether themes from concept maps and interviews matched, and similarities and differences in themes, concepts and utterances from concept maps and interviews were mapped for Annet. The network meetings and lesson observations were used to investigate where differences emerged and where similarities were strengthened.

Phase 4: Describing the results by themes. The ultimate aim was to gain an overview of the differences in Annet’s practical knowledge before and after the intervention, using Shulman’s (1986a) categories referred to in §4.2.1. In the course of the process of triangulation the existing categories were adapted in the framework of this study (cf. Glaser & Strauss, 1999). The arising categories are leading in describing Annet’s practical knowledge.

The arising categories were connected to the ICMTPG, thus providing insight into the underlying processes. This means that we described the chains of events occurred using the domains of the model.

4.5 Results
In this section we focus on Annet’s development during school year 2007-2008 (round 2), which became visible in the analysis of concept maps, interviews, network meetings and lessons.

4.5.1 Network meetings and lessons
During the network meetings teachers agreed that the teaching design would be collaboratively improved. During the last network meeting of round 1, teachers made a list with suggestions for improvement and this list was used as a source for revisions during the network meetings of round 2. In round 2, a new group of teachers (with exception of Annet)
tried to reach agreement on teaching goals, necessary revisions and the program of the lessons, taking into account the suggestions for improvement from round 1.

In short, the most important changes implemented in the new design were:

1. Pupils worked in pairs rather than in foursome.
2. The introductory assignment was adapted to serve as an introduction to the measures of centre and explained what statistical research is by providing an example.
3. The assignment was changed from open to semi-open. Pupils chose their own topic out of a list of three. Within this topic they devised their own research question.
4. The introduction and use of Excel was excluded from the teaching design, because it took too much time.
5. The progress of pupils was tracked in a less-detailed way by leaving out pre-structured logbooks and the progress diagram.

The first network meeting was used to explore each other’s ideas. During the later network meetings a new introductory assignment was shaped, assuming that this assignment would better fit pupils’ knowledge and notions about statistics. The program was detailed per lesson and agreements about the implementation were made, such as the number of lessons and the activities per lessons. Learning objectives were formulated particularly concerning pupils’ collaboration skills and their understanding of statistical concepts.

Furthermore, the meetings were used to divide tasks, such as redeveloping the introductory assignment and redesigning the teacher manual. The teachers produced draft versions of the introductory assignment and the teacher manual, which were discussed in the second network meeting. Discussions resulted in suggestions and ideas to be incorporated in improved drafts, which were discussed in the third and fourth meeting until consensus was reached. The teaching design was implemented after the fourth network meeting and the evaluation of the topic was planned to occur in the fifth network meeting.

Annet needed a total of nine, instead of six, lessons to complete the teaching design. She introduced the research project to her pupils during the first lesson. As intended, she provided an example of what the pupils could expect. In the first lesson pupils chose one of the possible topics. In the next lesson, pupils came up with the corresponding research questions. After approval of their plans they conducted their research in pairs and created the final product: a poster with their research data. Annet monitored the pupils’ progress by keeping them to their plans. In the ninth and last lesson, the pupils presented their posters and were allowed to ask
critical questions about the posters made by other groups. Annet supervised this process and made sure that the pupils did not just throw comments at each other but rather asked critical and informative questions.

For practical reasons Annet decided, after having consulted her colleagues, to implement the improved teaching design in the 8th grade rather than in the 7th grade. Annet, individually, tailored the teaching design to the requirements of her pupils, thus deviating from the agreements made in the group. Further, during the first lesson she used an instruction video for demonstrating statistical concepts. She also depicted the median by letting all pupils stand in a queue of increasing shoe size. Moreover, Annet introduced the computer program Excel in her lessons. During the implementation of the teaching design she shared her ideas with two other members of the network who did, or did not, took over her ideas. This illustrates that Annet is confident to improvise during the lessons, thus adapting the lesson plan to the present situation in the classroom, as an example of ‘Knowledge of context’.

4.5.2 Annet’s practical knowledge
Data from different sources were combined to analyse Annet’s practical knowledge (see phases 1-4, section 4.4.3). Annet’s practical knowledge is presented in table 4.3. Concept maps, discussion of concept maps and subsequent interviews led to the identification of a number of opinions held by Annet. These were arranged in small number of themes (second column of table 4.3). Discourse during network meetings and lessons observations revealed other aspects of Annet’s practical knowledge (fourth and fifth column of table 4.3). The data obtained could be grouped into the following categories: ‘selection of learning materials’, ‘providing feedback to pupils’ and ‘group assignment’. These categories correspond with types of practical knowledge within Shulman’s pedagogical content knowledge. In the last column of table 4.3 we give examples of statements by Annet, mostly from network meetings and discussions of concept maps.
## Table 4.3: Categorization of themes mentioned by Annet

<table>
<thead>
<tr>
<th>Category</th>
<th>Theme</th>
<th>Summary of teachers’ agreements during network meetings 1–4</th>
<th>Practical knowledge of Annet visible in lessons</th>
<th>Examples of statements by Annet illustrating her practical knowledge</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Selection of learning material</strong> – this is related to the teacher’s knowledge of the statistics domain and will affect the choice of the assignment for the pupils and the statistical concepts they will present to the pupils. (Shulman (1986a): Pedagogical content knowledge: Knowledge that is...</td>
<td>Learning and teaching statistical research skills</td>
<td>1. The assignment has a semi-open character.</td>
<td>1. Annet mentions that pupils should be free to choose any topic they want. In retrospect she mentions that this is much more interesting for the pupils as well as for the teacher. Likewise, pupils find it very difficult to choose a suitable research question (lesson 2).</td>
<td>1. ‘The list of topics was restricted, but that did not yield anything. These pupils found it difficult to formulate a research question for a given topic. It’s not the topic that’s the problem.’ (from CM[2]) ‘Pupils find it very difficult to choose a research question’. (from N5)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2. The introductory assignment for the pupils is exemplary so that they will know what to do when they are asked to set up and implement a research project themselves.</td>
<td>2. A short movie helped to explain the meaning of statistics to the pupils (lesson 1).</td>
<td>2. ‘(...) And that short movie really made statistics more clear’. (from N5)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3. Concepts are discussed during the lessons.</td>
<td>3. There is more room for the introduction of statistical concepts. For example, the median was introduced by</td>
<td>3. ‘Adopt, they must adopt these concepts, but they do not succeed yet’. (from N5)</td>
</tr>
<tr>
<td>Required for representing and formulating the subject to make this subject comprehensible to the pupils.</td>
<td>Lining up students in order of shoe size (lesson 1).</td>
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<tr>
<td>4. The pupils will not use the computer program Excel to handle data statistically.</td>
<td>4. The construction of circle diagrams by hand takes a lot of time. Annet therefore decides that pupils may use the computer to handle their data statistically (lesson 3).</td>
<td></td>
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<tr>
<td>4. – 'It’s much better that we find that out for ourselves. We are capable of discovery learning also! I instantly used the computer, we cannot work without it.' (from Int[2]) - - 'Using the computer just yields time. I just as easy revealed that point.' (from N5)</td>
<td></td>
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</table>

<table>
<thead>
<tr>
<th>Providing feedback to pupils – there is a direct link to the chosen procedure and the choice of the type of assignment.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Role of the teacher ↓ Inquiry-based teaching</td>
</tr>
<tr>
<td>In a research plan pupils make a time schedule.</td>
</tr>
<tr>
<td>Annet discovers that pupils find it difficult to have an overview of all research activities (lesson 2).</td>
</tr>
<tr>
<td>'A substantial difference was that I did not consider the loss of these log forms and also about pupil work leaving the classroom. Their work has to stay in the classroom, otherwise it can get lost or someone cannot go to work for a lesson.' (from CM[2]) 'And the question is, do we expect that they can do this?'. (from Ni)</td>
</tr>
</tbody>
</table>
**Group assignment**  
- teachers have opted for a group assignment for pupils that intends to promote collaboration between pupils and stimulate problem-solving skills.

(Schulman: Pedagogical content knowledge: Introducing and applying a new procedure. A special teacher-pupil interaction is needed, for there is no matter of whole-class teaching.)

<table>
<thead>
<tr>
<th>Collaboration</th>
<th>1. The teaching concept developed and the associated objectives are very suitable for group work. It is expected that pupils collaborate best in pairs.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1. Annet discovers that there is little discussion among pupils when they work in pairs. Besides, work is not done when one of the pupils is not present during the lesson (lesson 2).</td>
</tr>
<tr>
<td></td>
<td>2. Pupils present their research results and ask each other critical questions about their posters.</td>
</tr>
<tr>
<td></td>
<td>2. Annet discovers during lesson 7 that pupils where very capable to ask each other critical questions about research results. During the presentations pupils where giggling a bit. The presentations were short and of poor quality.</td>
</tr>
<tr>
<td></td>
<td>2. 'I cannot decide what I think is best for the pupils as for group size. Groups of four and groups of two both have advantages. I think that there is more discussion in groups of four. It is absolutely profitable to collaborate with fellow pupils and it is also important that pupils learn to collaborate during math classes'. (from CM[2])</td>
</tr>
<tr>
<td></td>
<td>'Working in pairs is really not good enough. I thought, I give it a try. Perhaps working in groups of three pupils is the right group size'. (from N5)</td>
</tr>
<tr>
<td></td>
<td>1. 'I wonder whether or not I will do the presentations again. I do not think that I will delete them completely, but they were not really profitable'. (from N5)</td>
</tr>
</tbody>
</table>

In table 4.3, we find some contradictory statements made by Annet, indicating changes that took place during the period of the intervention. One example, in the upper row, is that in the category ‘selection of learning materials’ she initially agreed with the group to restrict the topics pupils could choose, but during lesson 2 and in her last concept map discussion she changed her opinion. Something similar happened on the use of Excel. Initially, the teachers agreed not to use this software but during her lessons Annet decided to use it to save time for the pupils. This change was both visible in the concept maps and in her lessons.

Another example is the theme of ‘(student) Collaboration’. This theme is absent in CM[0], appears in CM[1] and gets a prominent role in CM[2]. Another new theme ‘Inquiry-based teaching’ arises in CM[2]. This theme indirectly implies a changing role of the teacher, and the theme ‘Role of the teacher’ therefore disappears in CM[2]. On the other hand, the themes ‘Evaluation’ and ‘Introduction of statistical concepts’ disappear in CM[2] compared to CM[1].

Table 4.4 shows changes in Annet’s practical knowledge, over a period of two years. The changes are described for the three categories mentioned above and to ‘Commitment to the teaching design and to the group’, which fits in Grossman’s category ‘Knowledge of context’. The last four columns connect to the ICMTPG as these consist of descriptions of Annet’s activities within the different domains of the ICMTPG. The descriptions in table 4.4 are reproductions of the words of Annet by the researcher and therefore they are not literally.
Table 4.4: Changes in Annet’s practical knowledge

<table>
<thead>
<tr>
<th>Category</th>
<th>Changes in practical knowledge within this category and compared to round 1 are related to Annet’s domain of classroom practice</th>
<th>Annet’s domain of consequence</th>
<th>Annet’s new practical knowledge, at the end of round 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Selection of learning material (Shulman: Pedagogical content knowledge)</td>
<td>Pupils are restricted in their choice of a topic By letting pupils choose a topic out of a list of three, they will be able to start more quickly.</td>
<td>The restricted list of topics appeared to be inadequate in gaining time, because it took the pupils much time to formulate a good research question. Besides, the restricted list resulted in student projects which are more or less similar.</td>
<td>It is much more motivating for the pupils, and also for the teacher, to choose a topic they are really interested in. In retrospect, Annet suggested that guiding to a research question would help pupils a lot. A restricted list of topics is not necessary.</td>
</tr>
<tr>
<td>Pre-structured introductory assignment</td>
<td>The assignment provides an orientation to the inquiry method and to the statistical concepts that pupils</td>
<td>The orientation on statistical concepts was much better than during round 1. This was partially due to a video she showed.</td>
<td>In retrospect, Annet argued that the new introductory assignment contributed to the understanding of the</td>
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<tr>
<td><strong>Chapter 4</strong></td>
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<tr>
<td>103</td>
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</tr>
</tbody>
</table>

are expected to use when conducting their own research.

measures of centre. For example, the median came up in a meaningful way. Subsequently, explicit attention was paid to what statistical research is.

For example, the median came up in a meaningful way. Subsequently, explicit attention was paid to what statistical research is.

### Introduction of statistical concepts

Concepts are discussed during the course of the teaching design implementation. Concepts do not automatically come up during the research project. They have to be introduced before the pupils start their own research.

Annet indicates retrospectively that more explicit attention was paid to statistical concepts. However, she doubts whether or not pupils are able to apply these concepts in different situations.

Learning of statistical concepts is not very difficult to pupils, but applying these concepts all the more.

### The use of the computer program Excel

The use of the computer program Excel is essential for processing statistical data.

One of the requirements of the final product is that pupils should present at least one graph. Pupils do not necessarily need the computer program to process their research results, because calculations and drawings of graphs were very time-consuming. Annet therefore agreed.

Pupils need to use the computer program Excel to process their research results, because calculations and drawings of graphs were very time-consuming. Annet therefore agreed.

Annet retrospectively noticed this is a learning process for her and that she made a mistake by leaving out the use of the computer.

The computer is essential for processing statistical data.
Excel to process their research results. They can draw up the graphic representations by hand.

<table>
<thead>
<tr>
<th>Providing feedback to pupils (Shulman: Pedagogical content knowledge)</th>
<th>The role of the teacher: time-schedule</th>
<th>Pupils need to make a time-schedule of the expected time required to carry out their research plan.</th>
<th>Annet experienced that it is not easy to keep the students to their time-schedule, and she did not succeed in this in all cases.</th>
<th>In retrospect, Annet is in doubt whether producing a time-schedule is a fair thing to ask from pupils of this age.</th>
<th>Pupils need experiences and guidance from the teacher while planning their learning activities.</th>
</tr>
</thead>
<tbody>
<tr>
<td>The role of the teacher: log forms</td>
<td>Pupils have to write a plan for their research. This research plan contains a time planning. Teachers can refer to this plan to monitor the pupils so that log forms are unnecessary.</td>
<td>As Annet did not have the disposal of log forms, she was not always acquainted with pupils’ progressions.</td>
<td>In retrospect, Annet argued that she has to monitor the pupils’ progress by collecting and examining log forms and/or parts of the assignment after the previous lesson and return them to the pupils with her written feedback.</td>
<td>Teachers must not think too easily on their supervising role during the implementation of research assignments. Log forms are essential.</td>
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<tr>
<td>Group assignment</td>
<td>Collaboration between pupils</td>
<td>Pupils will work together in pairs on cooperation in pairs provokes little</td>
<td>Annet retrospectively mentions that perhaps</td>
<td>It takes more experience to find out which group</td>
<td></td>
</tr>
<tr>
<td>Commitment to the teaching design and to the group (Grossman: Knowledge about context)</td>
<td>Collaborating in a network of colleagues</td>
<td>Research results and critical questions</td>
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<tr>
<td>their own research and divide tasks among themselves.</td>
<td>Pupils will present their research results and ask critical questions about each other’s posters.</td>
<td>Pupils are very good in asking critical questions, without commenting on each other’s work. The presentations of the posters are disappointing and pupils could do this better than they did.</td>
<td>Annet retrospectively does not know whether or not to do the presentations again with pupils of this age and this level. However, it should not be left out.</td>
<td></td>
<td></td>
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<tr>
<td>(Shulman: Pedagogical content knowledge)</td>
<td>The added value of collaboration with colleagues is that one can complement the others.</td>
<td>This is a good team. Francis is very punctual and she wants to know exactly what to do. Edward likes to keep things more open to see how far he can go with his pupils.</td>
<td>In retrospect, Annet mentioned during round 1 had a strong hold on the teaching design. During round 2 she sometimes consciously didn’t get involved as much.</td>
<td></td>
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<tr>
<td></td>
<td>Presentation of research is important. It is motivating and stimulating for pupils.</td>
<td></td>
<td>Working in a network of colleagues is valuable. You always learn from each other and the process of developing a teaching design is different in collaboration than individually designing education.</td>
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</tbody>
</table>
Although changes did occur in Annet’s practical knowledge, a number of beliefs with regard to the teaching of research assignments appeared to be unchanged. During the entire period Annet stayed convinced of the importance to carry out research assignments during mathematics classes, because, she says, it is likely that pupils learn other things than concepts, like inquiry, presentation and collaboration skills. Furthermore, she stayed convinced that an inquiry-based approach will stimulate pupils to learn statistics. It is likely that her experiences have led to strengthening of these beliefs, but this could not be supported by our data.

4.5.3 Reflection and enaction

Annet explored a new teaching strategy (enaction of Annet’s initial exploration), reflected on the consequences of that exploration, and found that notable outcomes were improved student learning and motivation, and improved teacher learning such as increased knowledge of the introduction of statistical concepts and the use of statistical computer software in research assignments. According to Clarke and Hollingsworth (2002, p.960), these changes in practical knowledge, as described in table 4.4, are considered as examples of teacher growth. Examples of enaction are also shown in table 4.4. During the intervention Annet enacted the ideas generated in the network meetings and her classroom experiences in the revised design and in her teaching practice. This is shown in Figure 4.3 by arrow 6. During round 1 this teaching strategy was new to her. Annet decided to reuse this teaching strategy in round 2, which represents the enaction of a newly developed belief in student ability to learn statistics when working in collaborative groups. Annet’s enactions are described in the sixth column of table 4.4.

A new teaching strategy, together with new research assignments, a changing role in the classroom and also the working in a collegial network are all new components of Annet’s teaching practice. Having experimented, and reflected on these experimentations, and interpreting the events in the classroom in terms of outcomes that she valued, Annet draws new conclusions. This is designated in the ICMTPG as the ‘domain of consequence’ and is considered as the reflective link between the domain of practice and the personal domain (see Figure 4.3, arrow 3).
4.6 Conclusions and discussion

4.6.1 Annet’s changes in practical knowledge

This study focuses on the question whether we can identify a development in Annet’s practical knowledge during her participation in a network of colleagues for two contiguous years. It appeared that we found a number of categories in which growth of knowledge became evident, most of them connected to Shulman’s pedagogical content knowledge (1986a). This practical knowledge is important in designing and implementing inquiry-based teaching and is about issues like organisation and supervision of group work, the degree of openness of assignments and the information students need to perform the task successfully and how teachers should provide this information to their students. We should bear in mind that this teacher did not work with inquiry-based teaching before and that the practical knowledge in this area is new to her. We expect that she will further extend her practical knowledge in future experiences, since she has shown to be open to experiment in the classroom.

Additionally, we found some changes in Grossman’s category ‘Knowledge of context’, which are related to Annet’s commitment to the group and to the assignment. Annet joined both the network meetings in 2006-2007 and in 2007-2008, and it appeared that Grossman’s category originated from the second year’s experiences. Thanks to her ‘Knowledge of context’ Annet was confident to deviate from the initial plan. She decided to use the computer, contrary to agreements made during the network meetings. This is an example of the so-called ‘Reflection-in-action’ (Schön, 1983), the process that allows us to reshape what we are working on, while we are working on it. This is an interesting development, because Annet is now able to improvise and to deviate from the intended plans, taking into account the situation during the lessons. Such improvisation was not observed with the other teachers and Annet did not improvise during the implementation of the teaching design during round 1. We may conclude that, although her commitment to the group and to the teaching design was good, she has followed her own path in the execution of the teaching design.

In our research study, we offered, as recommended by literature, a professional development program that is active and meaningfully situated in Annet’s own classroom. Teacher change starts with the formulation of expectations and reflection on former experiences during the
network meetings. The most important changes originate from the implementation of the teaching design in the classroom, by means of discrepancies between expectations and experiences, such as the guiding role of the teacher, group work or the use of the computer program Excel (see also table 4.4). Reflection on the formulated expectations during the network meetings and during and after the lessons resulted in knowledge acquired during a process of two years. This is expressed in the fact that after each intervention, Annet’s ideas were more sharply defined and she had a clearer picture of the learning material to be selected, the feedback to be provided to pupils and the ways to promote collaboration between pupils.

4.6.2 The Interconnected Model of Teacher Professional Growth
An operationalization of the ICMTPG is presented in Figure 4.3. We explain how we used this model for describing professional growth of Annet, by firstly describe a number of ‘cycles of change’. These cycles result from findings from the second round and can be traced in table 4.4. Secondly, we give an overview of the different processes during the first and the second round.

Cycle of change: Chain 2 → 5 → 7 → 9 → 4
Annet explored a new teaching strategy during the network meetings. She contributed to these meetings by using her practical knowledge that was partly based on her former experiences with the first teaching design (arrow 2). Arrow 5 represents Annet’s enaction of the design. Annet reflected on the consequences of that implementation, as represented by arrow 7, and decided that notable outcomes of the implementation of the design were improved student learning and motivation, and her increased satisfaction. Arrow 9 represents Annet’s reflection on the constituted outcomes of this exploration. This led to changes in practical knowledge regarding the value of this strategy (arrow 9), and consequently the inclusion of the strategy as a part of Annet’s practice. Arrow 4 represents the application of the new practical knowledge (via enactment) as a regular feature of Annet’s practice, to be further refined through Annet’s on-going experimentation and consequent reflection. In other words, arrow 4 means that decisions made by Annet during the lessons are based on her practical knowledge.
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Cycle of change: Chain 8 → 6 → 3
Clarke and Hollingsworth (2002) state that teachers use their practical knowledge in experiences that lead to new conclusions (salient outcomes). Annet uses her practical knowledge to model her newly acquainted conclusions drawn from the first round (arrow 8). These conclusions will affect her classroom practice during the second round (arrow 6). The new experiences, after implementing the improved teaching design, give rise to reflection and to an adjustment of her practical knowledge (arrow 3).

Cycle of change: Chain 5 → 7 → 6 → 3 → 4
Annet developed a new teaching strategy during the network meetings. Arrow 5 represents Annet’s enaction of the strategy: this represents the newly developed practical knowledge during round 1 that, according to Annet, this strategy is a useful and valuable experience for pupils during mathematics classes. After the implementation of the teaching design, Annet reflected on the consequences of that implementation, as represented by arrow 7, and decided that notable outcomes were improved student learning and motivation, and increased satisfaction with respect to her teaching. Furthermore, Annet enacted her conclusions during the implementation of the teaching design (arrow 6). This cyclic process of reflection and enaction during teaching (arrows 6 and 7) refers to Donald Schön’s ‘Reflection-in-action’ (Schön, 1983). It helped her to reshape what she was working on, while she was working on it. At the same time, Annet reflected on the implementation of the teaching design by means of comparing expectations with experiences, influencing her practical knowledge (arrow 3). Arrow 4 represents the application of the new practical knowledge (via enactment) as a regular feature of Annet’s practice, to be further refined through Annet’s on-going experimentation and consequent reflection. This is an example of ‘Reflection-on-action’. Schön (1983, p. 26) mentions “We reflect on action, thinking back on what we have done in order to discover how our knowing-in-action may have contributed to an unexpected outcome”.

Some striking differences occur between the first and the second round of developing and implementing a (revised) teaching design:

- In round 1 the arrows describing the process of teacher change are mainly 2 (this is not yet firmly developed), 1, 5, 3, 7, 8, 9.
• In round 2 the process may be described by the arrows 2 (Annet’s contribution to the network meetings is stronger now), 4, 6 and 8 (also stronger than during round 1). Thanks to the growth of her practical knowledge, her enaction becomes more explicit (arrows 2, 4, 6 and 8). The result was that Annet was able to tailor the teaching and the design to the requirement of her pupils, and to adapt her actions more to the classroom context. Annet has a number of personal characteristics that might contribute to the success of the intervention. She is receptive to new ideas and she is not afraid of experimenting in her classroom. She has a high level of reflective skills, enabling her to learn from her own experiences. For her contribution to the network it is important that she is able to guide and stimulate her colleagues.

Answering the second research question (see §4.3.1), it appears that the ICMTPG is adequate in describing teacher change. Table 4.4 shows that the different domains can be distilled from our research data. The ICMTPG gives insight in the underlying processes of reflection and enaction. It is also clear that teacher change involves cyclic processes, as the described cycles show and that teacher change is connected to teacher growth (see §4.5.3).

4.6.3 The practical relevance of the Interconnected Model of Teacher Professional Growth

Several research studies reported about the use of the ICMTPG in teachers’ professional development. Justi and Van Driel (2006) use the ICMTPG as the framework for the establishment of the relationships between the different data gathered in characterising science teachers’ knowledge on models and modelling. They identify a more detailed definition of each of the domains in the context of their project, in order to facilitate the analysis of the data. Furthermore, they show that the ICMTPG was successful as a framework both to design a professional development project, and to analyze and understand the growth of teachers’ knowledge within the context of their project (p.448).

Goh and Yoon (2010) believe that teachers should be actively involved in professional growth through reflection and enactment and therefore they have chosen the ICMTPG as an analytical tool. Their study investigates the changes in instructional practice of an experienced science teacher over two cohorts of students. They compare changes in instructional practice when novel nanoscience content is taught in two consecutive years. They identify that the domains of consequence and practice play significant roles in the
adaptation of the innovation. The ICMTPG framework is used to interpret their findings and to map reasons for the changes.

Coenders, Terlouw, Pieters and Dijkstra (2010) refer to the External Domain of the ICMTPG when designing innovative teaching materials: “When the learning material has to be innovative, developers need to be able to draw on external resources for new ideas” (p. 537).

During the writing of the material, teachers learn by using five sources from the External Domain. As examples they mention (p.551) ’experiences from each teacher who acted as inspiration for the others’, ‘discourse during network meetings about produced materials and envisaged class use’ and ‘specific literature (e.g., on cooperative learning)’.

Anderson and Moore (2006) used the ICMTPG to inform the development and evaluation of a new course for teachers: the Certificate of Secondary Mathematics Education (CSME). They found evidence of change in the domain of practice, the domain of consequence and the personal domain for at least some participants. However, they notice, a more detailed analysis to find evidence of change and growth networks would require in-depth interviews and observations with these teachers.

Voogt, Westbroek, Handelzalts, Walraven, McKenney, Pieters and De Vries (2011) report the use of the ICMTPG to identify processes of teacher learning during the collaborative design of curriculum materials in the context of curriculum innovation. They conclude that the ICMTPG can be used to identify learning processes that are fostered by collaborative curriculum design in teams of teachers.

From the above we see applications of the ICMTPG in designing professional development programs for teachers. Another branch of research uses the ICMTPG as an analytical tool to interpret findings on teacher change and evaluating new teacher training courses. None of these studies report about drawing up cycles of change, derived from the actual research data to describe professional growth. Our study is therefore an important addition to existing research.

4.6.4 Implications of this study

Our intervention has a few features that made it successful (at least for one teacher), mainly for the reason that these features are linked to the (success of) everyday practice of the teachers. Regarding the organization of the professional development these features are:

- The network serves as a community in which teachers are invited to exchange their ideas and opinions.
The teachers involved are from the same school. This enforces collegiality and this creates commitment to the group and to the teaching design.

A teacher educator functions as a mediator, organising the meetings and providing information.

Regarding the teacher activities in the network the features of our approach are:

- Teachers design teaching materials by exchanging experiences and knowledge. They discuss pupils prior knowledge, structure of learning materials, and teaching objectives.
- Although teachers collaborate in the network, they individually make their own decisions on revising and implementing the teaching design.
- During network meetings, teachers discuss about alternative approaches, which leads to a founded choice.
- Teachers consider their own and others’ teaching practice critically and they monitor the quality.
- Enactment of teaching practices and reflection on experiences from the classroom has been a major ingredient of the network meetings. Processes of reflection and enaction are prerequisites for learning and these processes have to become ingrained.
- Teachers experience what does and does not work for their pupils in providing and applying statistical concepts. Statistical literacy includes basic and important skills that may be used in statistical information and research skills. These skills include being able to organize data, construct and display tables, and work with different representations of data. Statistical literacy also includes an understanding of concepts, vocabulary, and symbols (Garfield, delMas & Chance, 2003)

This study shows the value of a coaching approach in a network environment to improve teachers’ practical knowledge. Teachers are often inclined not to discuss what they offer to their students and why they do so. Our research shows that a network approach, guided by the ICMTPG, is more effective than the traditional workshop approach. The ICMTPG triggers reflection and enaction.
However, we found that there can still be made some progress:

- Teachers can be stimulated more to articulate their personal development goals and to use literature in the process of developing the teaching design.
- In the long run, regular consultation with colleagues encourages teachers to adopt a critical attitude towards their own teaching practice.
- It is recommended that teachers visit each other’s lessons during the period of implementation of the teaching design, to see how the lessons of colleagues proceed.

In further research we will analyse the interaction during network meetings to gain more insight into processes that initiate teacher change and that contribute to professionalization. Furthermore, since experimentation and reflection are also the building blocks of metacognitive knowledge, it would be interesting to study to what extent the experiences contribute to long term professional development.
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