2 Statistical research by 3 havo pupils: Developing statistical research skills


**Abstract**

Many schools are considering integrating a long-term course concerning investigation skills in their secondary mathematics education, from year 1 up to the final grades that prepare for university. However, the majority of schools lack clear ideas about how to alter their education practices.

This chapter reports on a research study in which 15-year-old pupils receive an opportunity to develop research skills while working on a statistical project. Pupils chose their own research topic, but they had to follow a well-defined investigative cycle. By way of learner reports, pupils reported on what they had learned about working on their own statistical project. The conclusion is that the investigative cycle that was presented to them was good enough for the pupils to work with. However, interpreting data with statistical concepts was more difficult, as well as pupils monitoring their own learning process by keeping a logbook. Moreover, the lack of teacher guidance in formulating the research question resulted in pupils not being able to fully explore the nature of relations between variables.

2.1 Problem definition and research questions

For decades, mathematics teaching in the Netherlands mainly focused on the acquisition of mathematics skills and techniques, particularly in the fields of algebra and differential calculus. When the Basisvorming was introduced in the first three years of secondary education in the Netherlands, problem solving by means of heuristic and graphic methods was given more room in the programme at the expense of formal mathematics and algebraic techniques and algorithms (Goffree, Van Hoorn & Zwaneveld, 2000). However, this attention to problem solving remained limited and consisted mainly of ‘dressed up maths problems’. Special ‘Integrated Mathematical Activities’ (in Dutch: Geïntegreerde Wiskundige Activiteiten) were introduced in the Basisvorming to develop the skill to describe and solve practical
problem situations using mathematics, and textbooks such as *Moderne Wiskunde* introduced research as an activity. In the senior years of havo and vwo, before the introduction of a new curriculum (In Dutch: *Tweede Fase*), there used to be a clear difference in the amount of attention paid to research skills in physics as opposed to mathematics (Pol, 1997). As a great deal of attention was paid to science practicals, *independent research* already had a prominent place in the final-year programmes in physics, chemistry and biology and a culture was developing where research skills were strongly emphasized.

The current programmes in upper secondary education of havo and vwo (see chapter 1) in mathematics and science subjects require pupils to conduct large practical assignments and complete a practical exam. For the subject of mathematics this regulation has encouraged thoughts about the development of research skills by means of research assignments, and as a result some schools are also thinking about a long-term developmental line with regard to research skills from year 1 throughout the secondary school career up until the final year of havo or vwo. The *Tweede Fase* thus shows a shift in focus from acquiring procedural mathematical knowledge to acquiring the more general problem solving skills. Pupils must acquire a wide range of skills – they have to learn to plan, to analyse and solve problems, to collaborate and to work independently. The skills they acquire should help them prepare for their future studies and/or jobs, and the acquisition of research skills is important in this respect (Rijborz, 2003).

It is, however, not quite clear what exactly these research skills comprise and how they can be systematically dealt with in the various school years. According to Stokking and Van der Schaaf (2000), research can be regarded as a complex task, assuming that pupils will learn optimally if they are enabled to conduct research in a realistic way and make their own choices, not only with regard to problem definitions and research design but also concerning the research location (in or outside the classroom) and planning. With an eye to the learning outcomes of havo/vwo final-year programmes, a certain degree of explicit attention will have to be paid to setting up and conducting mathematical research. However, it is not clear what the exact aims are of having pupils conduct Integrated Mathematics Activities, practical assignments and research assignments (Harskamp, De Haan & Van Streun, 2000). Harskamp et al.
(2000) state that it would therefore be a good idea to further analyse the entire set of aims and activities, investigate the practical setting and map a process that focuses on a more systematic and targeted development of the relevant research skills. It is, however, not just the perceived conceptual uncertainty about the desired aims that complicates the development of research skills. An additional problem is that the implementation of this type of activity in the regular educational setting strongly depends on the personal opinions of the teacher or the mathematics department (Witterholt & Van Streun, 2002).

The social relevance of statistics and statistical research has given the field of statistics a prominent position within the domain of mathematics. Statisticians as well as curriculum developers and researchers, each using their own terminology, state that statistics teaching should concentrate on research skills (statistical literacy, statistical reasoning), although they have yet to agree on a clear definition of statistical research skills. However, there is a certain degree of consensus that pupils develop research skills by conducting statistical research themselves.

The problem definition for the entire research project has two aspects:

1. Definition and operationalization of statistical research skills
2. Development and testing of criteria for an optimal learning path in which pupils acquire the relevant statistical research skills.

This chapter reports on a teaching experiment in four 3 havo groups, conducted by four maths teachers at one school. It will discuss whether definition and operationalization of statistical research skills is possible and whether the teaching design would fit within a learning path that enables pupils to acquire statistical research skills. The teaching design starts with an example provided by each teacher, after which the pupils work on a research assignment in groups, focusing on processing data by means of statistics. Pupils choose their own topic, draw up a research plan, conduct the research, draw conclusions and make recommendations.

The research reported on in this article aims to answer the following research questions:

1. How do 3 havo pupils use the acquired statistical knowledge in independently conducted statistical research?
2. How do 3 havo pupils use their acquired skills in working with a statistical computer program when conducting their own statistical research?
3. How do 3 havo pupils conduct their own research in relation to a previously completed investigative cycle?

4. Are 3 havo pupils able to monitor and reflect on the development of their own research skills?

5. To what extent are the chosen characteristics of the teaching design adequate in terms of answering the above-mentioned research questions?

2.2 Research skills

2.2.1 Mathematics competence

The research literature provides a number of important lines of approach for research into the acquisition of research skills in the domain of statistics. Pupils must not only acquire knowledge of statistical concepts, they also have to learn to reason and argue on the basis of these concepts. Competence in a certain subject field is defined as a basis of factual knowledge and skills linked to a network of concepts and organized so as to promote recognition, retrieval and application of knowledge relevant to solving the problem at hand. Attaching meaning, reflecting, monitoring and explaining to yourself as well as others are aspects of metacognition – see for example Kilpatrick, Swafford and Findell (2001), Donovan and Bransford (2005) and Bransford, Brown and Cocking (2000).

This study uses the mathematics competences formulated by Van Streun (2001). He summarizes mathematics competences as follows:

1. Knowing that: knowledge of mathematical facts and concepts, reproduction, techniques
2. Knowing how: approach to maths problems, application, research skills
3. Knowing why: principles, abstractions, rich cognitive schemata, overview
4. Knowing about knowing: reflection, monitoring, knowledge about your own knowledge and approach
5. Attitude: learning maths is fun, interesting, and I can do it.

The research skills in the field of statistics primarily belong to the category Knowing how. This includes research question formulation, analysis of the situation, a systematic research approach and developing a research design. When setting up and
implementing statistical research, pupils should be able to recognize facts and concepts (Knowing that) and to apply them to the new situation (Knowing how). Reflection and monitoring, and checking the actions taken, is a good strategy for pupils to explain and develop their own research skills (Knowing about knowing).

Research question 1 concerns knowledge of concepts and techniques (Knowing that) and research skills (Knowing how) that are needed in order to be able to conduct statistical research. Research question 2 concerns the use of computer programs (Knowing how) for generating data files and for converting these data files into tables and graphs. Research question 3 concerns the question to what extent pupils are able to adequately conduct statistical research (Knowing how, Knowing why). Research question 4 concerns the development of metacognition (Knowing about knowing). Research question 5 concerns the teaching that is designed to enable the development of the above-mentioned competences.

2.2.2 Statistical knowledge

Statistics teaching focuses on learning to reason with statistical concepts and attaching meaning to quantitative information. Statistics teaching includes interpreting data sets, data representations and statistical summaries of data. Many types of statistical arguments combine ideas about data and probability, which results in drawing conclusions and interpreting statistical results. Such arguments are based on key concepts such as distribution, measures of central tendency, spread, correlation, uncertainty, coincidence and sample survey. Garfield and Gal (1999) distinguish several objectives for pupils’ understanding and skills in the field of statistics, including understanding the research process and mathematical concepts as well as mastering skills in processing data, interpreting and critically assessing results and reasoning on the basis of statistical concepts.

Educational research from recent decades has revealed that the emphasis on calculating statistical measures and test statistics contributes insufficiently to achieving these objectives. Research by Pollatsek, Lima and Well (1981), for example, shows that being able to calculate a mean or median hardly reveals a pupil’s understanding of the underlying basic concepts. Mokros and Russell (1995) draw a distinction between pupils who reason on the basis of understanding and those who primarily calculate. Delmas and Liu (2005) studied the levels of understanding in
pupils who had been taught about the concept of standard deviation. Most of these pupils turned out to use a rule-oriented approach to comparing distributions instead of reasoning on the basis of their understanding of the standard deviation. Using specially developed software, the researchers attempted to stimulate students to come up with more and better statistical arguments.

Konold and Pollatsek (2002) emphasize that although most pupils will eventually be able to calculate means and medians, they have no idea how to apply and interpret them. Part of the problem lies in the fact that although these measures of central tendency are used as typical scores for data collections, they do not form a solid conceptual basis for representing the entire group, for example in comparison with other groups.

2.2.3 Statistical reasoning

The international literature does not appear to use one term for statistical research skills. Usually terms like ‘statistical literacy’, ‘statistical reasoning’ and ‘statistical thinking’ are used. In a small-scale experiment, Pfannkuch and Rubick (2002) studied statistical thinking (observations, think aloud, interviews) among pupils who were conducting a structured research assignment. Pupils turned out to spend a lot of time thinking about data, learning about the data in order to construct representations and constructing data representations. The experiment resulted in a number of relevant descriptions of pupil argumentations, in which the teacher accurately probed for the meaning of representations and arguments.

Chance (2002) provided a review of recent definitions of statistical thinking and subsequently formulated this summary of ‘mental habits’:

1. Consideration of how to best obtain meaningful and relevant data to answer the question at hand;
2. Constant reflection on the variables involved and curiosity for other ways of examining and thinking about the data and problem at hand;
3. Seeing the complete process with constant revision of each component;
4. Omnipresent skepticism about the data obtained;
5. Constant relation of the data to the context of the problem and interpretation of the conclusions in non-statistical terms;
6. Thinking beyond the textbook.
Garfield (2003) developed an instrument to assess how pupils reason with statistical concepts and attach meaning to statistical information. She formulates the nature of statistical reasoning as follows: ‘Much of statistical reasoning combines ideas about data and chance, which leads to making inferences and interpreting statistical results. Underlying the reasoning is a conceptual understanding of important ideas, such as distribution, centre, spread, association, uncertainty, randomness, and sampling’ (Garfield, 2003, p.23).

### 2.2.4 Research skills

Statistical research skills can be regarded as a dimension of ‘statistical literacy’ (Gal, 2002) or ‘statistical thinking’ (Wild & Pfannkuch, 1999). Wild and Pfannkuch (1999) refer to the ‘investigative cycle’ (see figure 2.1) as one of the dimensions of conducting statistical research. This investigative cycle *concerns the way one acts and what one thinks about during the course of a statistical investigation* (Wild & Pfannkuch, 1999, p.225).

![Investigative cycle](image1.png)

*Figure 2.1: Investigative cycle*

The elements of this investigative cycle are similar to the research phases that pupils follow when they independently conduct a statistical research project. Table 2.1 provides an overview of the various pupil activities for each research phase.
Table 2.1: Phases in the investigative cycle versus pupil activities

<table>
<thead>
<tr>
<th>Phase</th>
<th>Pupil activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Problem</td>
<td>Pupils define the problem and formulate the research question.</td>
</tr>
<tr>
<td>2. Plan</td>
<td>Pupils draw up a plan of approach for their topic. They think about the following questions: Which data should be collected? How are data collected? What is the design of the research? What do we need in order to answer the research question? What do we need in order to analyse the data?</td>
</tr>
<tr>
<td>3. Data</td>
<td>Pupils implement the plan of approach – they collect data and think about how to process these data.</td>
</tr>
<tr>
<td>4. Analysis</td>
<td>Pupils process their data. They analyse the data they have collected, checking whether all data are useful and whether there are any important extremes. They process the data with the computer and independently decide how to present their data.</td>
</tr>
<tr>
<td>5. Conclusions</td>
<td>Pupils interpret their results, using their previously acquired statistical knowledge. They look back on the problem and draw conclusions.</td>
</tr>
</tbody>
</table>

The 3 havo teaching design in this study is mainly based on reasoning and arguing on the basis of statistical concepts discussed with the pupils in a preparatory phase (see section 2.3). Pupils subsequently conduct a statistical research project including a research question, experimental design, collecting and arranging data, comparing groups, finding relations, drawing conclusions and reporting. The research literature discussed above contains sound arguments for this method of teaching research skills.
According to Wild and Pfannkuch (1999, p.225), ‘Thus, the ultimate goal of statistical investigation is learning in the context sphere’.

2.3 Characteristics of the teaching design

More and more studies in the domain of statistics use software adapted to or specially designed for pupils in their curriculum design, shifting the focus from calculating to reasoning. McClain and Cobb (2001), for example, developed a teaching method in which pupils actively worked on collecting and interpreting data in meaningful contexts via assignments and using software. Their study focused on reasoning using the ‘big ideas’ of statistics, with pupils using computers to analyse data as well as to deal with mathematical concepts. The study aimed to develop the skill of logical reasoning about ways to structure data into conclusions. It focused on pupils’ ways of reasoning within one dataset as well as making comparisons between two datasets. The researchers reported that the pupils regularly entered into discussions about the approach, the suitability of the statistical measures to be used and the meaningfulness of conclusions in light of their contexts.

Bakker and Gravemeijer (2002) and Bakker (2004) used computer programs known as minitools to stimulate reasoning skills with regard to data distribution in first-year secondary school pupils. These minitools were designed to support the various elements of the concept of distribution as one coherent whole. Bakker and Gravemeijer defined four types of meaningful activities: data collection, growing samples, having pupils design graphs and ‘what if’ questions.

Doerr & English (2003) presented a detailed analysis of pupils’ thought processes when finding relations between different amounts, from which they concluded that pupils are very well able to select, order and weigh data. Based on their review of research literature and their own research, they emphasized that pupils should conduct their own little research projects and collect data in order to experience which statistical methods they need to know and be able to apply in a meaningful way.

Research assignments enable dovetailing education with a changing society in which IT is becoming increasingly important (Van den Akker, 2003a). In addition, such assignments may help increase intrinsic motivation in both pupils and teachers, who get to work without their textbooks (Van den Akker, 2003b). Chance (2002), based on her analysis of studies conducted, argued that pupils must learn statistical research skills by means of conducting their own research and
gathering their own data. ‘Students quickly see the difficulties associated with such a task: Do we have an appropriate measurement tool? (…) Students clearly see the messiness of actual data collection so often ignored in textbook problems. Students also have a higher degree of ownership and engagement with such assignments. (…)’ (Chance, 2002, p.5).

Based on the literature, the following characteristics of the teaching design have been formulated:

A. Preparatory phase

Time needed: 6 to 8 lessons of 50 minutes each to discuss the Statistics chapter from the book (see point 1 below), a 50-minute introduction to a statistical computer program (see point 2 below) and one half-day for following an investigative cycle under supervision (see point 3 below).

The literature discussed above revealed that mastery of statistical concepts (Garfield, 2003), the ability to analyse data using a computer program (McClain & Cobb, 2001) and the ability to follow an investigative cycle in a structured manner (Pfannkuch & Rubick, 2002) are preconditions for the ability to independently conduct statistical research. The following characteristics of the preparatory phase for statistical research conducted by pupils can be derived from the research literature discussed:

1. Pupils are introduced to statistical concepts (measures of central tendency: mean, mode, median) and graphical representations (bar charts, line charts, pie charts, scatter plots (known by pupils as point clouds) and box plots). Although the measures of central tendency and a number of these graphical representations were already discussed in previous years, the point clouds and box plots are new.

2. Pupils learn to work with a statistical computer program (Excel, VU-Statistiek).

3. Pupils follow an investigative cycle under supervision, based on a given problem definition.
B. Pupils do their own research project

Time needed: a day and a half for the entire process from thinking up a topic to creating the poster.

The investigative cycle discussed below is based on what was stated in section 2.2 as well as on a number of recommendations formulated by Doerr and English (2003), Chance (2002), McClain and Cobb (2001) and others.

1. In groups of four pupils, each pupil contributes two research topics, after which a brainstorming session will result in one topic plus research question, which is substantiated in writing and the teacher provides feedback on the choice made. The pupils present their choice to some or all of the other groups.

2. Each group makes a research plan. The teacher provides feedback. The pupils present their choices to some or all of the other groups.

3. Halfway through the process, the group reports to the teacher for written interim feedback on their progress. The teacher provides suggestions for adaptations to the plan of approach and further steps.

4. After each meeting, the group draws up a work report in the form of a logbook, in which problems are identified, plans are compared to the actual implementation, etc. The teacher provides feedback on this logbook.

5. The data collected by the pupils are processed with a statistical computer program.

6. Conclusions are drawn from the data, summarized on a poster and presented.

C. Reflection using a learner report

Time needed: Filling in a learner report will take 20 to 30 minutes.

Before and after the statistical research, pupils must fill in a learner report (Van der Kamp & Van der Kamp, 1982) on what they have learnt about conducting statistical research.
Chapter 2

2.4 Method

2.4.1 The choice for 3 havo and the participants in the study
Pupils are introduced to the field of descriptive statistics in the junior years of secondary school. The measures of centre (mode, mean, median) and distribution are discussed, as well as various graphical data representation types (bar charts, line charts, pie charts, point clouds and box plots). The third year comprises an introduction to drawing conclusions based on statistical data and their representations. Independent statistical research is usually not part of the program.

The reason we chose to conduct this study in 3 havo is related to the great differences in mathematical skills among the pupils, all of whom must continue to take the subject in their 4th year. Many maths teachers find it difficult to motivate their pupils in these years. The field of statistics in particular does not rely heavily on prior knowledge, which means that all pupils should be able to master the necessary skills. At the same time, however, the choice of this particular pupil population does make certain demands of the motivational aspects of the teaching design, like getting to work without their textbooks (Van den Akker, 2003b) or working in groups.

The teaching design was implemented with all 3 havo pupils at a broad secondary school with general and pre-university tracks in the countryside of the province of Groningen, which has two 3 havo groups each year. A total of 97 pupils participated in the study, which was conducted in school years 2002-2003 and 2003-2004. The implementation took place on two consecutive days in a project week, under the supervision of a total of 8 teachers, each of whom was responsible for two pupil groups. The teaching design was accompanied by a teacher manual that was handed out to the teachers in advance. Discussions with the teachers before the start of the project revealed that they had no high expectations of the dedication, motivation and results for these classes.

2.4.2 The teaching design
The teaching design for 3 havo pupils was based on the characteristics discussed in Section 2.3. The pupil assignment is described on the next page.
Pupil assignment

The following objectives were handed out to the pupils in writing as part of the assignment:

1. You will complete an assignment in a group, thus learning to collaborate, divide tasks and make plans.
2. You will learn how to tackle a mathematics research assignment.
3. Your research will result in a poster that you will create and present together with your group.

The pupil assignment:
Together with your group you will create a poster on the topic that you have chosen to investigate.

You will proceed through the following phases:

1. Choose a topic and submit it to the teacher for approval. N.B. Each topic can only be studied by one group. Make sure you will be able to study a connection. For example, rather than just studying the average weight of all 3 havo pupils, you should try to find out whether there is a connection between the pupils’ weight and the number of hours per week they play sports. You will be handed a sheet of A3 paper to write down your chosen topic.
2. Next, you will make a research plan together with your group and submit it to the teacher for approval. Think about which material you will need to create your final product and formulate one or more research questions.
3. You must report on all the activities performed in your group every day in a logbook, which you must hand in to the teacher at the end of each day. He or she will then sign your report and store the logbook. Once your topic and plan have been approved, you will have a meeting with two other groups and the teacher in a classroom, where you will present your topic and plan to everyone present.
4. The next step is to conduct the research. If you have any questions, consult your teacher.
5. You must also report to your teacher halfway through the project for an interim check to make sure you are on the right track.
6. The final product is a poster. At the end of the second project day you will present your group’s final product to the other two groups and the teacher. The posters will be put up in the maths classroom.

Requirements for the final product:

1. Mathematics: Choose a good title that clearly shows the connection studied. Ensure accurate display in diagrams using VU-Statistiek and draw the right conclusions. Make sure that all essential information is presented. This means, among other things, that you must include a measure of centre and use VU-Statistiek and the diagrams in this program.
2. Attractiveness: How does the poster look? The poster must look good in terms of layout, use of colours, structure and language use.
3. Collaboration among group members: the logbook must indicate how the group members worked together. The logbooks must be accurately kept. Has everyone made a sufficient contribution?
The topics chosen and the associated results can be compared to data from the Nationale Doorsnee, a huge database containing information about over 50,000 pupils on a wide range of research topics and data, such as body height, breakfast habits, hours spent on sports, watching TV and playing on the computer, favourite school subject, income from part-time jobs and pocket money, and favourite pop stars. The Nationale Doorsnee was introduced on the occasion of the year 2000 being designated World Mathematical Year by UNESCO (=United Nations Educational, Scientific and Cultural Organisation).

2.4.3 Collecting research data

The following data were collected in the implementation of the teaching design:

2.4.3.1 Written test

Pupils made a written test about statistical concepts (mean, mode, median) and graphical representations of frequency data (bar charts, line charts, pie charts, point clouds and box plots). Descriptive statistics pays very little attention to the concept of ‘distribution’. Although representations in box plots and point clouds are introduced, more emphasis is placed on the ability to calculate measures of centre and to create the specified diagrams. Starting in 4 havo, pupils shift from descriptive statistics to the more formal side of statistics, for example when they learn about normal distribution (see also Bakker & Gravemeijer, 2002). The concept of distribution is then explicitly discussed.

Before the teaching experiment, pupils discussed the Statistics chapter in the book. They learned to calculate measures of central tendency (mean, mode, median) and create graphical representations of given data. The chapter concluded with a written test, in which pupils had to calculate measures of central tendency and draw diagrams. The teacher administered and marked the test. It is important to this study that pupils are able to calculate measures of centre and draw various different graphical representations.
2.4.3.2 Observations

Pupils and groups of pupils were observed both in the preparatory phase and during the investigative cycle. Teachers were also observed during their instruction to groups or to individual pupils. The researcher was present during the preparatory phase and during the phase in which pupils worked independently to fill in observation forms.

Observations related to the preparatory phase:

- Observations of lessons focusing on working with the computer program VU-Statistiek. Pupils worked in pairs on a computer practical assigned to them, in which they learned to enter data into the computer and subsequently calculate measures of centre and draw graphical representations with the program VU-Statistiek.
- Observations of the implementation of the investigative cycle. Pupils proceeded through the various phases of research, from writing a plan of approach to drawing conclusions, under supervision.

Pupils or groups of pupils and teachers were observed during the implementation of the teaching design:

- Observation of group discussions among four groups of pupils.
- Observation of the brainstorming session about the choice of research question and completion of the associated A3 form by the pupils.
- Observation of the development of the plan of approach and completion of the associated A3 form by the pupils.
- Observation of the three presentations on the chosen topic, the plan of approach and the poster respectively.
- Observations of teachers guiding pupils during the research process

Two groups of pupils were alternately observed for ten minutes at a time. During these observations, notes were made on a pre-printed form with regard to what the pupils are working on, which subjects they have discussions about, whether they need help and, if so, what for, where they look for help and what the teacher’s influence is. In addition, the group’s work progress and the distribution of tasks within the group is also a point for attention.
2.4.3.3 Written pupil products

Pupils created a number of products in the course of the study, including:

- Learner reports: Pupils indicated before and after the project whether their competence in the field of twelve research skills had increased or decreased (see table 2.2). In addition, blank spaces have been left in the report forms where the pupils could add remarks.

- A3 form for topic selection. During the topic brainstorming session, the pupils jotted down the suggested topics and their final choice of topic on the A3 form. The teacher subsequently provided feedback and signed the form for approval.

- A3 form for drawing up a plan of approach. During the plan of approach brainstorming session, the pupils jotted down the suggested plans and their final plan of approach on the A3 form. The teacher subsequently provided feedback and signed the form for approval.

- Logbooks: Pupils reported on their progress of the research on a preprinted logbook. They reported on the distribution of tasks within their group, the topic they were working on, the agreements they made, the questions they discussed, the problems they encountered and the questions that the group liked to discuss with the teacher. The teacher checked the logbooks, provided feedback and signed it for approval.

- Posters: The poster was the final product of the pupils’ research project. The pupils chose the appropriate measures of centre and graphical representations for the research data they had collected, summarized the results and drew conclusions.

2.4.3.4 Teacher feedback

The teachers provided written interim feedback on the groups’ progress via a preprinted form, before every new lesson. They should have asked their pupils whether they were working according to their original plan, whether the plan needed to be adapted, whether all pupils were performing their tasks properly, whether there were any changes within the group, whether the group had sufficient time to conduct the research and whether the pupils had sufficient information (in terms of both knowledge and organization) to perform the tasks. At the end of the project the
teachers were asked to complete a questionnaire with questions about how their maths classes usually proceed and how this differed from the way of working during the implementation of the teaching design.

2.4.4 Data analysis

The research data were analysed by summarising the research questions (see Section 2.1) in relation to the data sources. The data sources are printed in italics.

Research question 1: Which statistical knowledge do 3 havo pupils acquire in independently conducted statistical research? After the preparatory phase, the degree of mastery and the ability to use statistical prior knowledge was demonstrated via the written test. The teachers assessed the written tests and assigned grades according to an established rubric. All posters have been analysed, focusing on whether the chosen measures of centre and graphical representations matched with the data collected by the pupils.

Research question 2: How do 3 havo pupils use a statistical computer program? Pupils were observed while working with a statistical computer program both in the preparatory phase and during the implementation of the teaching design. During the observations, I checked if:

- pupils were able to enter data in the statistical computer program;
- pupils were able to calculate measures of central tendency for the data they entered;
- pupils were able to draw graphical representations for the data they entered;
- pupils asked for help while working with the computer program;
- bottlenecks occurred while pupils were working with the computer program.

Research question 3: How do 3 havo pupils conduct their own research in relation to a previously completed investigative cycle? I used A3 forms, topic presentations and group observations to check whether pupils could choose a topic independently. Together with the presentations of plans, A3 forms and (group) observations I checked if pupils could draw up a research plan of approach and to what extent the plan of approach was affected by the teacher’s
feedback. *Observations* and *logbooks* were used to check if pupils were able to independently implement a plan of approach. Pupils’ progress was described by using *observations* and *logbooks* and teacher’s written feedback to the pupils. *Observations, posters* and *poster presentations* were useful in showing whether or not the chosen measures of central tendency and graphical representations matched with the data and research questions, and the conclusions on the posters matched with the collected data and research questions.

Research question 4: *Are 3 havo pupils able to monitor and reflect on the development of their own research skills?* 
*Logbooks, observations* and *learner reports* provided means to observe to what extent pupils were able and willing to monitor their progress and if they were able to indicate their own development.

Research question 5: *How adequate is the teaching design, in terms of contributing to the operationalization of statistical research skills?* 
*Observations, logbooks, teacher feedback, learner reports* pupil remarks listed in the *learner reports* were useful in tracing bottlenecks that occurred during the implementation of the teaching design. The *teacher questionnaire, observations, and pupil remarks listed in learner reports* also gave a clue in addressing pupils’ motivation while working on their own research.
2.5 Results

2.5.1 Using statistical knowledge
It appeared that the pupils acquired sufficient knowledge (‘Knowing that’, see Section 2.2) of statistical concepts and graphical representations during the preparatory phase to be able to complete the poster. The pupils were able to calculate measures of central tendency in the written test and on the poster and they drew various different graphical representations on the poster, such as pie and bar charts as well as box plots and point clouds.
An example of what pupils may include in their poster can be found in figure 2.2 below.

Pocket money: How much pocket money do 3 havo pupils get and what do they spend it on?
Results:
44 pupils
Mean = € 44.60
Median = € 30
Mode = € 30
Min = € 0
Max = € 100

Conclusion: ‘The results indicate that an average student gets about € 40 in pocket money and/or clothing allowance’.

Figure 2.2: An example of pupils’ findings on the poster

The pupil assignment (see Section 2.4.2) states that the pupils must study a connection between two variables. The posters indicated that most groups have failed to do this.
For example, in the research question ‘What eye colours do 3 havo pupils have?’; it is difficult to indicate a connection as there is only one variable (which is ‘eye colour’).
An example of a better research question here is ‘Do blond pupils more often have blue eyes than pupils with dark hair?’ In this example a connection can be studied between two variables (eye colour and hair colour).
2.5.2 Working with a statistical computer program

Although the pupils have demonstrated skills in using the computer program, named ‘VU-Statistiek’, during the preparatory phase, a number of bottlenecks occurred when conducting their own research. Pupils tended to forget how to enter their data and how to subsequently create a pie or bar chart. As a result, several groups changed to the more familiar program Excel to add graphical representations to their posters. Partly thanks to having sufficient computers available in the computer room and the media library, and in some cases also thanks to the change from VU-Statistiek to Excel, all groups managed to include one or more diagrams as graphical representations of their data.

2.5.3 Pupils conducting their own research

- The pupils held lively discussions to choose the topic they found most fun and most interesting to investigate. What makes a topic ‘fun’ is not only that it appeals to the pupils in itself, it also helps if they leave the classroom to gather their data, for example to interview their schoolmates in other classes. Examples of chosen topics include ‘What eye colours do 3 havo pupils have?’, ‘Which brand of toothpaste do 3 havo pupils use?’ and ‘What is 3 havo pupils’ favourite drink?’ The teacher’s feedback was mainly needed to clarify the research question. This was mainly done by asking the pupils’ questions, such as ‘What exactly do you want to find out?’, ‘Which questions will you ask to this end?’ and ‘Will you be able to find information about this topic?’ In a number of cases pupils were forced to choose a different topic to prevent too many similar topics being studied or because no suitable data could be collected in and around the classroom or school. The presentations were generally very brief and were intended to have the pupils explain why they made certain choices.

- The completion of the A3 form for the plan of approach went smoothly. The pupils discussed what would be the best plan of approach. The teachers provided feedback by asking questions, such as ‘Will you have to interview all the pupils in the entire school?’, ‘How will you collect information?’ and ‘Will you be able to complete this plan within the given time frame?’ Virtually no plans of approach were rejected by the teachers and more extensive plans of
approach were rarely requested. The presentations on the research plans were very brief and were intended to have the pupils explain their method. Pre-structuring the study to be conducted turned out to be very useful as it enabled pupils to look back on previous steps. The teacher could simply refer to the research plan, also because this was set out on paper.

- The teachers’ feedback enabled timely adjustments in order to ensure project progress. Several groups had to be prompted to start processing their data to prevent them running out of time before the poster presentations, whereas other groups were advised to divide their tasks as otherwise they would never be able to complete all the work.

- A number of bottlenecks occurred when entering and processing data with the computer program VU-Statistiek. As mentioned above, several groups had forgotten how to enter data and subsequently make calculations or create graphical representations. These groups changed to Excel, which they had more experience with.

- The posters indicated that pupils often opted for scatter plots to represent their data. However, this is not the best option for studies comprising small numbers of observations – in such cases, bar charts are a more suitable choice. Many posters also contained information that was not relevant to the research question. For example, the group that investigated how many sandwiches pupils take to school included a text about how bread is produced.

- Although pupils appear to be able to draw conclusions from their research, these conclusions are often rather simple because no connections are found between data. Most groups did not look for connections between their research data and the teachers were unable to guide them towards doing so. The group that investigated the connection between pupils’ travelling distance to school and the time they went to bed did succeed in this respect – they discovered that pupils do not go to bed earlier the further away they live. Another group studied 9th graders’ eye colours and only came up with numbers and percentages.

- The example in figure 2.2 indicates that pupils summarized their research data on the poster using the mean, whereas the mode would have been a more useful measure in this context. The mean provides an inaccurate picture of the
data due to a number of extreme scores. Several posters contained incorrect conclusions. This is undoubtedly partly due to the fact mentioned above, that pupils do not always use statistical concepts and graphical representations correctly.

2.5.4 Monitoring and reflection

- Group observations indicated that pupils regularly discuss the progress in various phases of the investigative cycle, thus acquiring insight into their own contributions. Questions like ‘What have we done so far?’ and ‘What do we still have to do?’ are regularly asked. The task distribution, in which each pupil had his or her own task, sometimes led to a lack of exchange of data and knowledge. Pupils who had processed data and created graphical representations on the computer often failed to discuss the chosen data representation type with other pupils who were assigned different tasks. Logbooks were often filled in quickly and incompletely and pupils did not tend to consider them to be a natural component of the investigative cycle.

- Table 2.2 provides a summary of the learner reports, in which the pupils report on the research skills that they have or have not acquired during the implementation of the teaching design. This table lists twelve research skills reported on by pupils. In addition to a number of general research skills (including ‘Task distribution’, ‘Making agreements’ and ‘Keeping agreements’ with regard to working in groups), they also include skills used for statistical purposes, such as ‘Collecting data’, emphasizing statistical data processing and interpretation, including the skills ‘Processing data into a story’, ‘Completing a written assignment’ and ‘Giving a presentation’. Pupils indicated to what extent they had mastered these skills before the start of the teaching design implementation and again after the project had ended. This way, pupils indicated their own development with regard to the relevant skills.
The following is a brief explanation of Table 2.2.

Although the project only lasted two days, the pupils reported significant improvements in certain skills. A number of skills are discussed in more detail on the next pages.

Table 2.2: Research skills, 3 havo teaching design, in absolute numbers and percentages (between brackets).

<table>
<thead>
<tr>
<th>Skills</th>
<th>Before and after</th>
</tr>
</thead>
<tbody>
<tr>
<td>Task distribution</td>
<td></td>
</tr>
<tr>
<td>Planning work activities</td>
<td></td>
</tr>
<tr>
<td>Making agreements</td>
<td></td>
</tr>
<tr>
<td>Collecting information on the internet</td>
<td></td>
</tr>
<tr>
<td>Keeping agreements</td>
<td></td>
</tr>
<tr>
<td>Estimating how long something will take</td>
<td></td>
</tr>
<tr>
<td>Collecting information in the library/media</td>
<td></td>
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<tr>
<td>Library/media</td>
<td></td>
</tr>
<tr>
<td>Holding discussions</td>
<td></td>
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<tr>
<td>Processing data into a story</td>
<td></td>
</tr>
<tr>
<td>Completing a written assignment</td>
<td></td>
</tr>
<tr>
<td>Giving a presentation</td>
<td></td>
</tr>
<tr>
<td>Finding out why something went wrong</td>
<td></td>
</tr>
</tbody>
</table>

Pupils indicated to what extent they felt they mastered skills 1 to 12 both before and after the teaching design implementation: G = 'Good', NG = 'Not Good', DK = 'Don’t Know'.

The data indicates significant improvements in skills such as organizing work, keeping agreements, and estimating how long something will take.
1. **Task distribution**: 67% of pupils indicated both before and after the project that they have mastered this skill (G→ G), and another 20% developed this skill during the project (NG→ G and DK→ G together).

2. **Planning**: 53% of pupils indicated both before and after the project that they mastered this skill (G→ G), and another 28% developed this skill during the project (NG→ G and DK→ G together).

3. **Making agreements**: No fewer than 73% of pupils indicated both before and after the project that they mastered this skill (G→ G), and another 8% developed this skill during the project (NG→ G and DK→ G together), whereas 12% of the pupils indicated after the project that they were not good at making agreements (G→ NG, NG→ NG and DK→ NG together).

4. **Collecting information on the internet**: 58% of pupils indicated both before and after the project that they mastered this skill (G→ G). However, 16% felt that although they initially thought they were good at looking things up on the internet, they turned out to find it more difficult in actual practice (G→ DK).

5. **Estimating how long something will take**: 19% of pupils indicated both before and after the project that they mastered this skill (G→ G), and another 30% developed this skill during the project (NG→ G and DK→ G together). Pupils appear to find this activity rather difficult. Although a significant development can be seen, 29% continued to have problems in this field.

6. **Processing data into a story**: 42% of pupils indicated both before and after the project that they mastered this skill (G→ G), and another 33% developed this skill during the project (NG→ G and DK→ G together). This significant increase is probably due to the fact that pupils were asked to draw conclusions and write summaries on a poster.

7. **Giving presentations**: 25% of pupils indicated both before and after the project that they mastered this skill (G→ G), and another 24% developed this skill during the project (NG→ G and DK→ G together), meaning the number of pupils who were confident about this doubled during the project.
8. Finding out why something went wrong: 29% of pupils indicated both before and after the project that they mastered this skill (G→G), and another 30% developed this skill during the project (NG→G and DK→G together). 34% of pupils were not sure whether they mastered the skill after the project (→DK).

2.5.5 Characteristics of the teaching design

- The investigative cycle in which pupils conduct their own research works well. Choosing a topic, writing a plan of approach, receiving feedback on the progress and, finally, creating a final product generally proceeded fairly smoothly.

A number of characteristics of the teaching design, however, have proven less successful. First, the preparatory phase pays no attention to the choice of statistical concepts and graphical representations. Pupils are sometimes unsure which measure of centre to use and why, and the same applies to graphical representations. The second problem lies in the logbook, which pupils did not tend to consider a natural component of their work. This means that the groups insufficiently discussed what they were doing and why they were doing it this way. Thirdly, the pupils’ insufficient mastery of the computer program VU-Statistiek led them to change to the more familiar application Excel during the investigative cycle.

- All completed posters were put up in the mathematics classroom and stayed there for several weeks as the pupils were very proud of their work. One girl asked whether the poster could stay up a bit longer as she wanted to show it to her friends from another class. Pupils indicated in the learner reports that they enjoyed doing research and that they would like to do this more often. In addition, most pupils indicated that what they enjoyed most about the project was working together with their classmates. The teachers were pleasantly surprised by the dedication and motivation demonstrated in these remarks, also because these pupils were sometimes difficult to motivate during ‘regular’ maths classes.

2.6 Conclusions and discussion

Looking back on the problem definition (see Section 2.1) we may conclude that the implementation of the teaching design has contributed to the operationalization of statistical research skills in a certain way. Statistical research skills were defined as a dimension of
‘statistical literacy’ or ‘statistical thinking’ and linked to pupil activities. Wild and Pfannkuch (1999, p.246) state that ‘In many research environments, statistical thinking is like breathing – everyone does it all the time, seldom being aware that it is happening. Statistics, the discipline, should be teaching people to "breathe" more effectively’. Having to fill in learner reports appears to make pupils more conscious not only of the problems that may occur when independently conducting research, but also of their own strengths and weaknesses in this field. Offering an investigative cycle is a good idea, although pupils still have trouble interpreting data by means of statistical concepts and monitoring their own learning process. A learning path has been developed where 3 havo pupils, who are just starting to learn statistics and often lack motivation in the field of mathematics, managed to choose topics that they were interested in, write a plan of approach in mutual consultation and enthusiastically conduct their own statistical research. This teaching design – with a few adaptations – would appear suitable as part of a longer learning path focusing on research skills.

Pupils should know that they should deliberately choose a measure of central tendency and a graphical representation that match the data. This study indicates that the fact that the Knowing that component has been covered does not necessarily mean that pupils have mastered the Knowing how aspect as well. Although the pupils were able to calculate measures of centre and draw graphical representations, they did not always draw the right conclusions from their research. This has also been discussed in the literature. According to Konold and Pollatsek (2002), although pupils are able to calculate measures of central tendency, they have no idea how to apply and interpret them.

The part of the assignment stating that pupils had to find a relation between two variables was insufficiently implemented. This was partly due to the fact that the pupils were insufficiently prepared for finding relations – relations between variables were not discussed in the preparatory phase. On the other hand, the teachers should have provided more guidance in the pupils’ choice of topic and intervened sooner if a research question is limited to a calculation problem. Most teachers have no experience in supervising statistical research, and teacher-training programmes tend to pay little or no attention to such supervision. As a result, teachers find it difficult to guide pupils towards a good research question that discusses the connections between variables.
Some of the problems indicated during the implementation of the teaching design, such as indicating connections in the choice of topic, filling in the logbook, introducing statistical knowledge and concepts and interpreting measures of central tendency, could have been solved if the teachers had provided more guidance. This issue can be solved by getting teachers involved in the development of the teaching design. The more teachers are aware of what is expected of them, the better they will be able to supervise their pupils in their research projects. Teacher competencies needed in guiding statistical research are: (1) having an overview of what statistical knowledge to be used by pupils, and when, (2) paying extra attention to correlation and representing differences between groups, (3) monitoring pupils’ metacognitive skills, for example by commenting on pupils’ log books, (4) ensuring that pupils exchange data, (5) paying attention to a research plan as a means to pre-structure pupils’ research, (6) using the most well-known computer program for pupils, so they can get started right away, and (7) guiding pupils in finding a research question and in presenting relevant information on the poster regarding the research question.

In this study, pupils worked with previously taught statistical knowledge and concepts. According to a study by Van Gerwen (2005), mathematical concepts should be thoroughly developed by the fourth year of havo, so that pupils can use their knowledge in a variety of assignments, including research assignments. The research aspect will not be covered if too much time is needed to explain concepts to pupils during the investigative cycle. Van der Sanden, Terwel and Vosniadou (2000), however, stated that mastery of statistical concepts can also be developed while working on research assignments. This way, pupils work on developing their own interconnected knowledge and skills.

Although pupils were able to calculate measures of central tendency and draw graphical representations, they still found it difficult to use their statistical knowledge in a functional way. Pupils may perhaps be better able to apply their knowledge to different situations and to interpret results if the statistical knowledge and concepts are not discussed until they ask for them. Finally, it should be pointed out that due to the distribution of tasks, data and knowledge were often not exchanged, which meant that not all pupils in a group were equally well aware of them. We should therefore aim for a situation where pupils realize the need for data and knowledge exchange, for example, by administering a final test to assess knowledge and skills.
Pupils used a statistical computer program to process data and create graphical representations of these data – the aspect of reasoning based on the available statistical knowledge is less successfully covered. McClain and Cobb (2001) and Bakker and Gravemeijer (2002) were more successful in this field with their educational computer programs. Statistical concept knowledge is developed while working with these programs, which is not the case for VU-Statistiek and Excel. VU-Statistiek and Excel are data processing programs. VU-Statistiek was specially developed for secondary education – this program is more user-friendly for the target group as it has fewer options than Excel.

This study indicates that pupils often forget how to work with VU-Statistiek and change to the more familiar Excel application to conduct their research. However, data processing with the computer is very useful because pupils often have a lot of data to process and manual calculation would be very time-consuming. In addition, these computer programs teach pupils to apply their knowledge. In order to better implement the computer program, it would be a good idea to integrate the computer lessons into the teaching design, instead of computer lessons in preparatory lessons. Pupils would then work on the computer when they are ready for it, rather than in preparation for the implementation of the teaching design. They would have all the necessary information at hand and would not have to change to a different program.

The presented investigative cycle (see also Millar (1989), Pijls, Dekker & van Hout-Wolters (2000) and Van Rens & Dekker (2000)) worked well for the pupils. One important factor is that pupils got to choose their own topics, which made the research interesting and relevant to them, as Van Rens (2005) indicates. Although forms provide useful information about the choices made by pupils, the number of forms used could perhaps be limited. This would mean, for example, that pre-printed forms for the choice of topic and the plan of approach would no longer be needed. In addition, it would be a good idea to use a cross-curricular investigative cycle. This would improve cohesion between subjects and the recognisability of the various research phases.

As most groups in this study failed to keep an accurate logbook, it can be concluded that the logbook did not function as intended. Logbooks offer pupils a way to reflect on their work and their way of working. According to Van Streun (2001), reflection and monitoring is a good strategy for pupils to explain and develop their own research skills (Knowing about knowing). A
logbook could be a valuable tool to this end. Harskamp et al. (2000) emphasize that pupils will only make progress on their way to the final target if the learning process is accurately structured. It would therefore be a good idea to reserve time for filling in the logbook at a fixed moment during the lessons. This way, the logbook will become an integrated, natural part of the teaching design. In the learner reports, pupils reported on the research skills that they had or had not acquired during the implementation of the teaching design. However, the question whether the pupils were able to apply the research skills they claimed they had acquired to another problem cannot be answered on this basis.

Teachers are important points of contact for pupils while conducting their research. The teachers’ feedback on the pupils’ choice of topic, the plan of approach and their progress stimulated them and thus was useful. Teachers indicated that they found it difficult to motivate their pupils during ‘regular’ maths classes, but that they demonstrated excellent dedication and motivation during the project. Pupils themselves also indicated that they enjoyed collaborating on a topic of their own choice and they would like to receive more of these research assignments. This different way of working in itself might motivate pupils more than ‘regular’ maths classes. In addition, the results of the work (i.e. the poster) were more visible to pupils and therefore offered a better indication than when they simply had to wait for (the grades of) the written test on a specific chapter. The positive experiences of teachers and pupils, may be a good foundation for further research.

The bottlenecks indicated provide insight into the pupils’ comprehension problems and implementation problems. The approach of conducting statistical research projects in class has turned out to be successful in many respects. One question that yet remains to be answered, however, concerns a curriculum for the development of statistical research skills for the entire secondary education path from year 1 to years 5 havo and 6 vwo. A programme of increasingly complex research projects will have to be developed. This study suggests that not all pupils were able to conduct research into connections between two variables – it appeared that they first should gain experience studying the distribution of one single variable. This provides an initial indication with regard to a possible learning line.
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