

# Experimenting matters

*Learning and assessing science skills in primary education*

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**Publication date**

2018

**Document Version**

Final published version

[Link to publication](#)

**Citation for published version (APA):**

Kruit, P. M. (2018). *Experimenting matters: Learning and assessing science skills in primary education*. [Research HvA, graduation external, Universiteit van Amsterdam]. Hogeschool van Amsterdam, Kenniscentrum Onderwijs en Opvoeding.  
<http://hdl.handle.net/11245.1/9e356b2b-dab1-411c-8bff-79558760af91>

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# EXPERIMENTING MATTERS

LEARNING AND ASSESSING SCIENCE SKILLS IN PRIMARY EDUCATION

Patricia Kruit

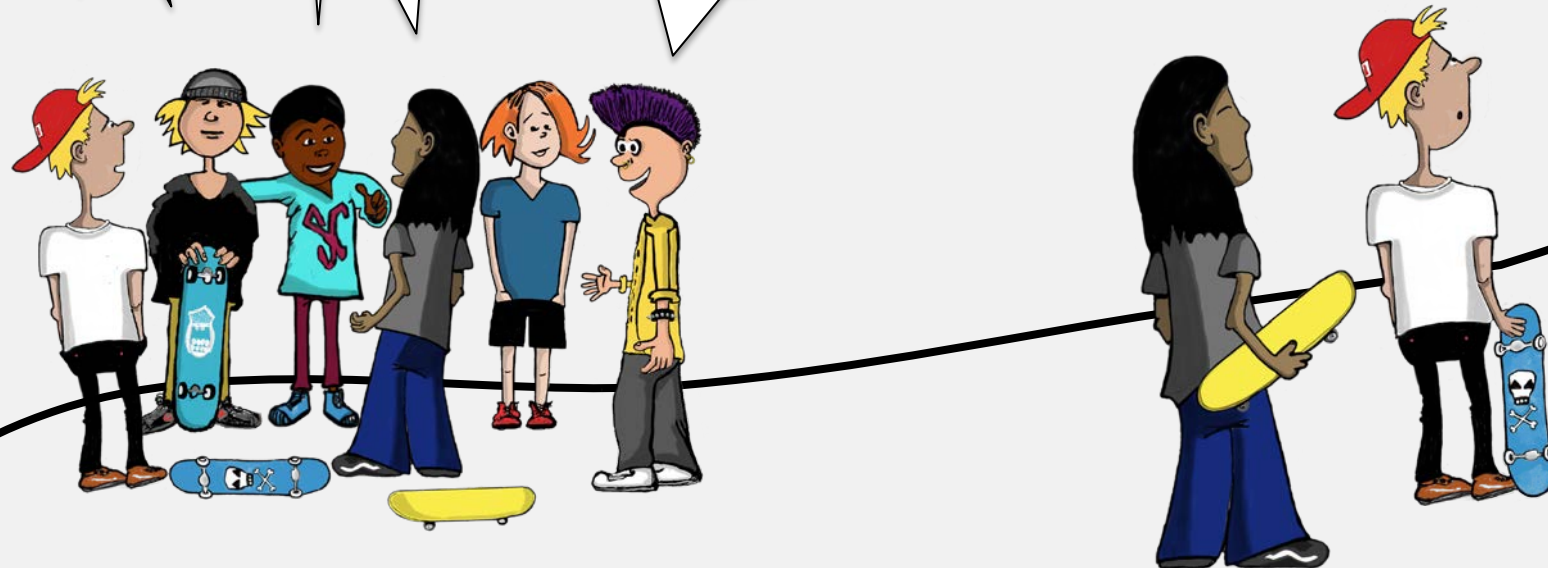
This dissertation aims to investigate the effectiveness of instruction methods on students' science skills in grades 5 and 6 of primary education in the Netherlands.

To assess the effects, measurement instruments for evaluating the acquisition of science skills have been developed.

Findings show that science lessons can improve skills when carefully structured and set up with opportunities to practice skills in scientific inquiry tasks.

Results indicate that explicit instruction on science skills is necessary for more robust acquisition of these skills.

So, this research provides a strong argument for including an explicit teaching method for developing science skills in primary education.



# **EXPERIMENTING MATTERS**

LEARNING AND ASSESSING SCIENCE SKILLS IN PRIMARY EDUCATION

Patricia Mariam Kruit

The research presented in chapter 3 in this thesis was also supported by a grant from the National Platform Science & Technology [Stichting Platform Bètatechniek] in the context of a Call for Proposals Science Skills (2015).

artwork:	Adrian Kruit
cover and lay out:	Arnold Koopman
printed by:	GildePrint
published by:	Kenniscentrum Faculteit Onderwijs en Opvoeding HvA
ISBN:	978-94-92497-04-8

# **EXPERIMENTING MATTERS**

LEARNING AND ASSESSING SCIENCE SKILLS IN PRIMARY EDUCATION

ACADEMISCH PROEFSCHRIFT

ter verkrijging van de graad van doctor  
aan de Universiteit van Amsterdam  
op gezag van de Rector Magnificus  
prof. dr. ir. K.I.J. Maex

ten overstaan van een door het College voor Promoties ingestelde  
commissie, in het openbaar te verdedigen in de Aula der Universiteit  
op vrijdag 23 november 2018, te 13.00 uur

door Patricia Mariam Kruit  
geboren te Palmerston-North, Nieuw-Zeeland

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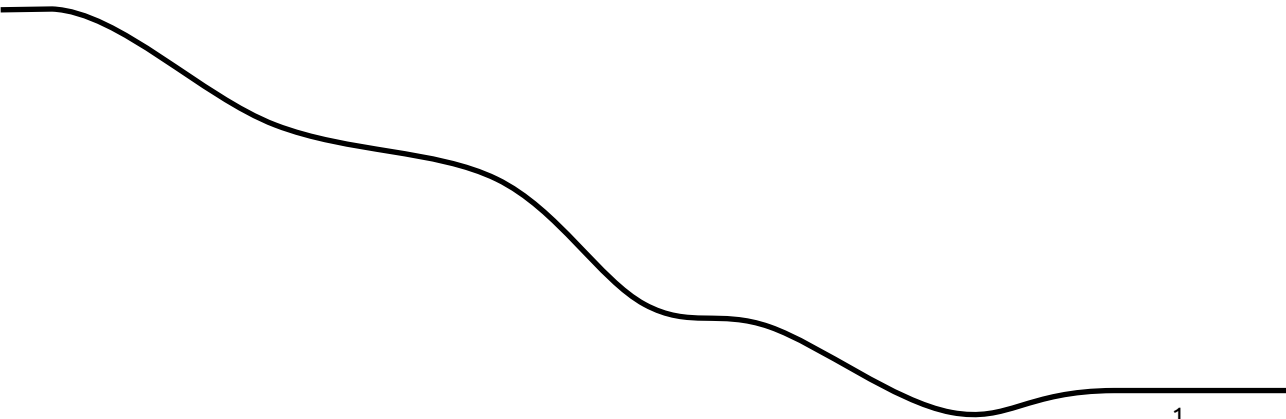


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## general introduction



Science and technology have been given a prominent position in primary education curricula in most countries. The aim of education policies (cf. OECD, 2015) is to strengthen innovation by improving science education and attracting more people to science, technology, engineering and mathematics (STEM). Since the 1960s, there has been an increasing emphasis on the acquisition of science skills, which can be described as the skills involved in generating and validating knowledge through scientific investigations. This coincided with the growing interest for active learning in schools. Excitement about conducting experiments and figuring out things was considered a necessity for realizing active learning and creating a positive attitude towards science and technology. Results of educational research progressively led to the understanding that, aside from achieving a positive attitude and acquiring content knowledge, learning science skills is an important objective in primary science education. This development is reflected in contemporary frameworks for science education (Dillon & Manning, 2010; National Research Council (NRC), 2012). Nowadays, the main goal of science education is for students to become scientifically literate citizens, defined by the Organization for Economic Cooperation and Development (OECD), 2013) as:

*An individual's scientific knowledge and use of that knowledge to identify questions, to acquire new knowledge, to explain scientific phenomena, and to draw evidence-based conclusions about science-related issues, understanding of the characteristic features of science as a form of human knowledge and enquiry, awareness of how science and technology shape our material, intellectual, and cultural environments, and willingness to engage in science-related issues, and with the ideas of science, as a reflective citizen. (p. 17)*

The OECD's definition implies that attitude, content and science skills need to be addressed in science education. Students must understand the necessary science concepts in order to explain phenomena and technology in their environment and develop content knowledge related to issues such as health, nutrition, environment and sustainability. More generally, students must appreciate science and understand its essential role in society. Additionally, they need to have an understanding of the nature of science through experiencing how knowledge is generated, improved and validated through scientific inquiry.



Development of science skills for scientific inquiry is therefore explicitly included as a learning objective in primary science education. In general, the science skills - also referred to with terms such as “inquiry skills”, “science process skills”, or “investigation skills” - are defined based on the activities in which scientists engage during authentic research (Lederman & Lederman, 2014). In the framework for K-12 science education in the U.S. for instance, scientific inquiry is represented by three domains of activities: investigating, developing explanations and solutions, and evaluating data as evidence for the proposed theories and models (NRC, 2012). The NRC emphasizes that students should learn about what scientists do while they design and carry out their own inquiries.

From this rationale, not only in the U.S. but also in European countries and Australia, educational documents and curricula have included learning goals related to conducting authentic scientific investigations (ACARA, 2010; Crawford, 2014). For instance, in the National Primary Curriculum for England, the goals aimed at learning to perform a scientific inquiry include “practical scientific methods, processes and skills” (Department for Education, 2013, p. 166). In the Next Generation Science Standards (NGSS) which are based on the framework for K-12 science education (NRC, 2012), the goals are described in the form of expectations for what students should know and be able to do (NGSS Lead States, 2013). The K-12 Framework and the NGSS refer to the elements addressing scientific investigation with the term “practices”. Practices are a reflection of the work and thinking of scientists as they “investigate and build models and theories about the natural world” ([www.nextgenscience.org/three-dimensions](http://www.nextgenscience.org/three-dimensions)). The term practices is used instead of skills to emphasize that “engaging in scientific investigation requires not only skills but also knowledge that is specific to each practice” (NRC, 2012, p. 30).

However, a large gap exists between what is specified in the goals of educational frameworks and the actual practice with regard to implementing science activities in primary schools. In many countries, little time is spent on science in classrooms due to the higher priority given to mathematics and language subjects. Even if science is taught, it is generally of low quality. The focus is on hands-on inquiry activities without paying much attention to relating the activities to scientific thinking (Roth, 2014). It is problematic that educators and teachers focus mostly on the practical aspects of scientific inquiry, such as observing, measuring, recording data, and handling equipment (Osborne, 2014). This limited operationalization of science skills neglects the teaching and practice of other important cognitive aspects involved in scientific investigation. For instance, using the skills in a scientific inquiry in particular demands self-regulation and the knowledge and use of metacognitive strategies (Zohar & Barzilai, 2013). Students need to acquire metacognitive skills in order to understand, monitor and evaluate their own higher-order reasoning and

thus stimulate scientific thinking (Kuhn, 1989). When designing effective teaching materials, it is important to define science skills by identifying the cognitive demands underlying these skills.

There is still an ongoing discussion regarding how science skills are most effectively taught in primary education. It is often so that inquiry is also presented as an instructional approach, aimed at learning science concepts as well as acquiring skills. As a result, the goals and the means to attain these goals are conflated. It is important to distinguish between learning to conduct a scientific inquiry and inquiry-based learning (IBL). In the former, learning to conduct an inquiry is the educational goal. In the latter, IBL is a teaching method in which science skills are prerequisites or are assumed to be acquired along the way. Using inquiry as an instructional method to teach science does not necessarily mean that students will learn the skills to perform these inquiries simply by doing it. Although there is evidence pointing to the acquisition of skills through learning by doing (Dean & Kuhn, 2007), a growing number of studies indicates that explicit instruction may be necessary to develop inquiry skills (Klahr & Nigam, 2004; Lazonder & Harmsen, 2016; Toth, Klahr, & Chen, 2000). Due to their lack of experience and limited mastery of strategies, skills and knowledge, students in primary education need support and scaffolding to effectively conduct a scientific inquiry. It may be that explicit skill instruction will lead to more effective performance of scientific inquiry (Klahr & Nigam, 2004; Kirschner, Sweller, & Clark, 2006).

In this thesis, the focus of the research is on the acquisition of science skills by using explicit instruction. To our knowledge, few studies have investigated science skills acquisition by comparing explicit instruction with a teaching approach in which the aspects of explicit instruction are absent. In this research project, these instructional approaches are compared. In addition, several studies have investigated the effects of explicit instruction on skill development in a laboratory-based setting, in particular on the strategy of controlling variables (CVS). To attain higher ecological validity, the present research has been conducted in real-life physical classrooms.

With the increased attention toward the implementation of inquiry activities within primary science classrooms, a growing interest has emerged in assessing students' science skills. Research has been concerned with the limitations and advantages of different test formats. Most tests are paper-and-pencil formats consisting of multiple-choice items. These tests are easy to administer and score, and students are familiar with the format (Harlen, 1991). However, a disadvantage of paper-and-pencil tests is that they generally do not reflect the activities of a real-life scientific inquiry (Davey et al., 2015). In line with an increased understanding of how students learn, performance assessments have been



considered as an alternative. With performance assessments, students execute small experiments which reflect the conditions under which scientists' work and solve problems (Shavelson, Solano-Flores, & Ruiz-Primo, 1998). While performance assessments are considered more authentic (Davey et al., 2015; Ennis, 1993) they are also more cost and labor-intensive to administer and due to the open format, reliable rating is complicated (Davey et al., 2015).

Of major concern is the lack of convergence between different test formats (Baxter, Shavelson, Goldman, & Pine, 1992; Baxter & Shavelson, 1994; Hammann, Phan, Ehmer, & Grimm, 2008; Lawrenz, Huffman, & Welch, 2001; Roberts & Gott, 2006) and between tests with similar formats intended to measure the same science skills (Gott & Duggan, 2002; Pine et al., 2006). The small correlations that were found between tests have been attributed to differences in students' content knowledge (Gott & Duggan, 2002; Shavelson, Baxter, & Pine, 1991), but also to inconsistencies in rating and occasion sampling variability. Occasion sampling variability occurs when students perform the same task differently on different occasions (Ruiz-Primo, Baxter, & Shavelson, 1993). These findings imply that underlying cognitive demands may not be equally evoked (Messick, 1994; Millar & Driver, 1987; Shavelson et al., 1991). In this thesis, we will add to the current understanding by designing and discussing the validity and reliability of different assessment instruments. Unlike in previous research, assessments instruments will be designed by taking into consideration underlying cognitive demands.

Another important matter regarding the assessment of science skills is the usage of tests in science classrooms. Most of the assessments that are administered in science classrooms are routinely used written tests for summative evaluation of students' progress (Black & Atkin, 2014). Teachers spend a considerable amount of time with summative assessments but fail to implement formative assessments which could have been used to guide their instruction and to improve students' learning. In particular, the use of performance assessments may be beneficial for formative evaluation of students' science skills. By structuring performance assessments according to the various steps involved in regular scientific experiments, opportunities can be created to provide teachers with diagnostic information. This diagnostic information is not only important for teachers to improve their teaching but also to provide (individual) students with adequate feedback.

In the 80s, performance assessments were implemented with the purpose of obtaining information on students' performance, such as in the Assessment of Performance Unit (APU). In the STAR (Science Teachers' Action Research) project, the aim was to improve practice in science education at the primary school level (Schilling, Hargreaves, Harlen, & Russell, 1990). Particular attention was given to students' performance during practical

activities. Here, teachers carried out systematic observations to yield information on students' achievement. In a study by Aschbacher and Alonzo (2006), a performance assessment was used to investigate how teachers use the students' science notebooks and how teachers' feedback and guidance in the classroom was improved by professional development. The present thesis will add to these findings by highlighting aspects of performance assessments which are particularly valuable for improving science teaching practice. As argued by Davey et al. (2015), instruction and assessment are equally important in students' learning.

### **The present thesis**

The aim of the present research project is to seek ways to improve both teaching and assessment instruments in primary science education. It starts with a definition of science skills in which the various cognitive demands are taken into account. By adding to the existing body of knowledge relating to the learning, teaching and assessing of science skills, the present thesis may shed light on more effective teaching and assessments methods, thus strengthening students' scientific literacy. Accordingly, instructional methods were examined which may facilitate the acquisition of science skills for grades 5 and 6 primary school students. Assessment instruments were developed to measure students' acquisition of science skills. The following overall research questions were addressed:

1. What are science skills and how can they be operationalized?
2. What are crucial components of an instructional design for teaching science skills?
3. How can students' ability in performing scientific inquiry be validly and reliably measured?
4. What are the effects of explicit instruction on students' acquisition of skills in scientific inquiry?
5. What is the added value of performance assessments as a diagnostic tool to guide instruction in science classroom practice?

### **The Dutch context**

The research of the present thesis was carried out in the Netherlands. Primary education includes two years of kindergarten starting from the age of 4 and the following six years of formal education from grade 1 (age 6) through 6 (age 12). In the Netherlands, *science & technology* is part of the curriculum domain called *world orientation*. World orientation





includes geography, history, and science & technology (Inspectorate of Education, 2015). Science & technology aims at developing a positive attitude towards conducting inquiry as well as developing science skills, content knowledge and knowledge about the nature of science. In particular, a learning objective in the Dutch primary curriculum is to develop the skills to perform a scientific inquiry on a variety of natural phenomena. However, the Royal Netherlands Academy of Arts and Sciences, an advisory body to the Dutch Government, expressed great concerns about the decreasing amount of time spent on science & technology in primary schools as well as the students' decreasing performance. Furthermore, a mere 16% of the schools monitor the students' performance of skills associated with performing a scientific inquiry in the context of science & technology (Inspectorate of education, 2015). The ministry of Education, Culture and Science has announced their aim to stimulate the implementation of science & technology in 2020 in all primary schools (van Graft, Klein Tank, & Beker, 2014).

### **The outline of this thesis**

This thesis consists of six chapters of which four chapters are research articles. The research articles have either been published in an international journal (chapters 3, 4 and 5) or have been submitted for publication (chapter 2). Writing a thesis in articles has both advantages and disadvantages. One advantage is that each chapter can be read separately. A disadvantage is that there can sometimes be overlap between chapters and that the term consistency may not always be optimal.

In chapter 2, we present a study in which an instructional design for teaching science skills is discussed in order to answer research questions 1 and 2. The design is based on the categorization of science skills into three types of cognitive skills: thinking skills, metacognitive skills and science-specific skills. It is argued that systematically incorporating explicit instruction and practice of the separate skills will support students more adequately in their acquisition of science skills. An outline of an instructional framework with a detailed lesson example is provided and discussed.

Chapter 3 addresses the third research question. This chapter focuses on measuring the progress in the acquisition of science skills. For this purpose, different instruments were constructed including a paper-and-pencil test, three performance assessments and two metacognitive self-report tests. The results of 128 5<sup>th</sup> and 6<sup>th</sup> grade students were used to discuss the validity and reliability of these tests.

In chapter 4, the fourth research question is addressed. We discuss an intervention study that examined the effects of explicit instruction on the acquisition of inquiry skills.

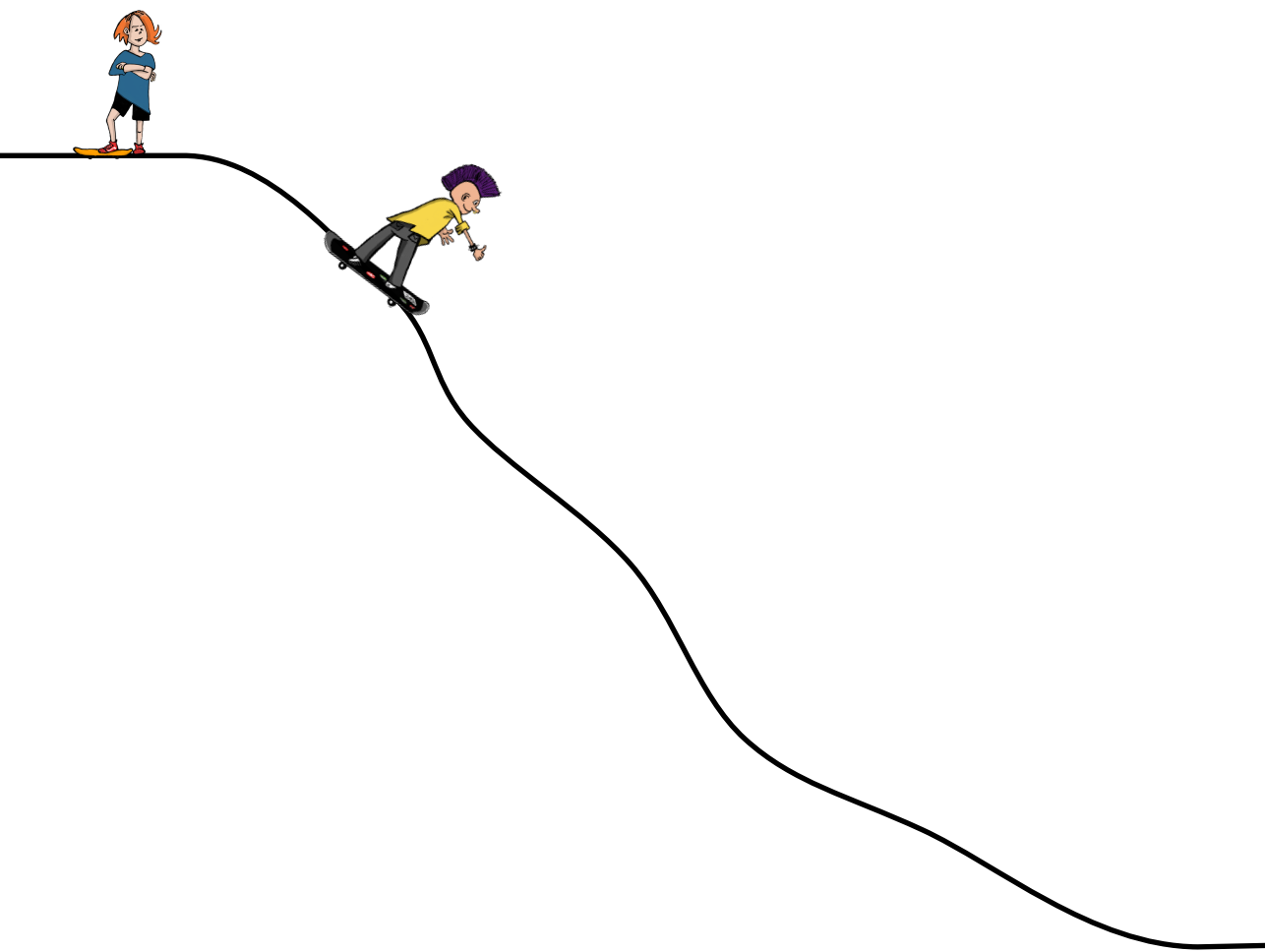
The intervention and the design of the study were based on insights discussed in chapter 2. The effects of the intervention were measured using the instruments examined in chapter 3. The effects of the explicit instruction intervention were compared to conditions in which students either followed their regular science curriculum or received instruction based on learning by doing. Multi-level analysis was applied to examine effects of both instructional methods.

Chapter 5 provides a closer look at the results of the performance assessments in order to gain insight into students' answers. The study was aimed at discussing the value of performance assessments as an educational tool for formative assessment of science skills in the classroom.

Finally, in chapter 6 we discuss the findings of the different studies. Limitations and suggestions for future research are offered and implications for educational practice are considered.







an instructional **framework**  
for teaching science skills  
in primary science education

# ABSTRACT

The purpose of the study is to develop and discuss an instructional framework for teaching science skills in primary education. Science skills are usually - if at all - taught by instructional methods primarily based on learning by doing despite evidence suggesting that more explicit teaching methods and strategies may be more effective. Most teachers focus on only the practical aspects of scientific inquiry which results in a disregard of a wide variety of cognitive abilities called upon in scientific investigations. For this reason, science skills were defined based on the different cognitive demands which underlie a scientific inquiry: science-specific skills, thinking skills and metacognitive skills. Due to their lack of experience and limited mastery of strategies, skills and knowledge, students in primary education need support and scaffolding to effectively conduct a scientific inquiry. An instructional framework was developed based on the four-component instructional design model of Van Merriënboer, Jelsma, and Paas (1992). Accordingly, the lessons included whole learning tasks and part-task practice to enhance integrated application of skills. It was demonstrated how to design a high quality explicit instruction for primary school in which not only the practical but also the cognitive part of scientific inquiry is emphasized. The demonstration included a description of the form and the content of the lesson design informed by the literature and a detailed example lesson. Categorizing the general concept of science skills in thinking skills, metacognitive skills and science-specific skills provided the opportunity for designing and constructing teaching materials in a systematic way.

## Based on

Kruit, P. M., Oostdam, R. J., van den Berg, E., & Schuitema, J. A. (submitted). An instructional framework for teaching science skills in primary science education.



## 2.1 Introduction

In most countries, science and technology have been given a prominent position in primary education curricula. Since the 1960s, there has been an increasing emphasis on the acquisition of science skills - the skills involved in generating and validating knowledge through scientific investigations - which coincided with the growing interest for active learning in schools. Excitement about doing experiments and figuring out things was considered a necessity for realizing active learning and creating a positive attitude towards science and technology. Results of educational research progressively led to the understanding that, aside from achieving a positive attitude and acquiring content knowledge, learning science skills is an important objective in primary science education. This development is reflected in contemporary frameworks for science education (Dillon & Manning, 2010; National Research Council (NRC), 2012). Nowadays, the main goal of science education is for students to become scientifically literate citizens, defined by the Organization for Economic Cooperation and Development (OECD), 2013) as:

An individual's scientific knowledge and use of that knowledge to identify questions, to acquire new knowledge, to explain scientific phenomena, and to draw evidence-based conclusions about science-related issues, understanding of the characteristic features of science as a form of human knowledge and enquiry, awareness of how science and technology shape our material, intellectual, and cultural environments, and willingness to engage in science-related issues, and with the ideas of science, as a reflective citizen. (p. 17)

The definition of the OECD implies that attitude, content and science skills need to be addressed in science education. Students must understand science concepts which are necessary in order to explain phenomena and technology in their environment and develop content knowledge related to issues such as health, nutrition, environment and sustainability. Additionally, they need to have an understanding of the nature of science through experiencing how knowledge is generated, improved and validated through scientific inquiry. More generally, students have to appreciate science and understand its essential role in society.

In recent policy and curriculum documents, the narrow emphasis on attitude and content knowledge has shifted to a more balanced concept of science education in which knowledge about scientific methods, attitude, content knowledge and science skills are equally important (European Commission, 2007; Next Generation Science Standards (NGSS)

Lead States, 2013; Department for Education, 2013; OECD, 2013). Therefore, curricula in most countries describe the learning objectives for science education not only in terms of acquiring content knowledge but elaborately for science skills as well.

Science skills are usually - if at all - taught by instructional methods primarily based on learning by doing (Duschl, 2008; Roth, 2014). In the Netherlands for instance, inquiry-based learning is advocated in primary education as the preferred method for acquiring content knowledge, science skills and epistemic knowledge (van Graft & Kemmers, 2007). The assumption underlying inquiry-based learning is that students learn science the same way scientists work. However, as remarked by Kirschner, Sweller and Clark (2006) "The practice of a profession is not the same as learning to practice the profession" (p. 83). Recent research suggests that different instructional methods and strategies may be more effective and that science skills need to be taught in a more systematic and explicit manner (Klahr & Nigam, 2004; Lazonder & Harmsen, 2016).

Furthermore, Osborne (2014) argues that it is problematic that educators and teachers mostly focus on only the practical aspects of scientific inquiry (e.g., observing, measuring, recording data, handling equipment), which applies to both primary (Roth, 2014) and secondary education (Osborne, 2014). This limited operationalization of science skills results in ignoring the wide variety of cognitive abilities called upon in scientific investigations. For instance, handling a microscope taps into other abilities than identifying patterns in data. Because of this, science lessons frequently contain activities in which predominantly the practical side of inquiry is emphasized. For designing effective teaching materials, it is important to define science skills by identifying the cognitive demands underlying these skills and to teach these skills in an explicit and systematic manner.

The aim of this study is to illustrate in what way structured lessons can be designed when taking into account the various cognitive demands and how the various skills can be taught. For this reason, an instructional framework was designed for developing primary students' science skills of which the general concept of science skills is categorized by the underlying cognitive demands.

In the following sections, the theoretical background of the instructional framework for designing science lessons for primary education is discussed. First of all, a further operationalization of science skills is specified and a distinction is made in thinking skills, metacognitive skills and science-specific skills. In addition, recent theoretical and empirical research on students' learning of science skills is explored to substantiate the instructional framework. Finally, the framework is illustrated by way of describing one particular lesson out of the total of eight lessons designed for the purpose of an effect study with a pretest-posttest design.





## 2.2 Defining and learning science skills

Science skills - also referred to with terms such as “inquiry skills”, “process skills” or “investigation skills” (Harlen & Qualter, 2009) - usually indicate a wide variety of activities related to planning and conducting investigations and interpreting results (Alonzo & Aschbacher, 2004; Gott & Duggan, 1995; Harlen & Qualter, 2009). Abrahams and Reiss (2015) additionally make a distinction between skills such as planning, predicting, and experimenting, as opposed to practical skills which are more specific such as handling a microscope.

Science skills are generally defined based on the activities scientists engage in during authentic research (Lederman & Lederman, 2014). In the framework for K-12 science education, scientific inquiry is represented by three domains of activities: investigating, developing explanations and solutions, and evaluating data as evidence for the proposed theories and models (NRC, 2012). The model reflects the notion that research is not a linear process consisting of fixed steps but that instead scientists go back and forth between the “three spheres of activity” (p. 44).

### **Science skills and cognitive demands**

Current literature generally encourages the consideration of skill categories in scientific inquiry (Duschl, Schweingruber, & Shouse, 2007; Schraw, Crippen, & Hartley, 2006) because it is important to identify and define accurately the cognitive demands underlying the inquiry activities for teaching science skills. In general, the broad concept of science skills can be further categorized in science-specific skills, thinking skills and metacognitive skills.

Science-specific skills refer to the ability to apply procedural and declarative knowledge for correctly setting up and conducting a scientific experiment (Gott & Murphy, 1987). These skills can be classified as lower order thinking (Newmann, 1990), or reproductive thinking (Maier cited in Lewis & Smith, 1993), and are characterized by recall of knowledge, comprehension, routine rule using and simple application (Goodson, 2000). Students performing a scientific inquiry have to recall the facts and rules about how to conduct scientific experiments, such as identifying and controlling variables, observing and measuring, using simple measurement devices. They then have to use and apply the knowledge for, for example, selecting the appropriate procedures and organizing the data in tables (Gott & Murphy, 1987; OECD, 2017). Science-specific inquiry skills defined as such

encompass the practical skills as discussed by Abrahams and Reiss (2015), but pertain to cognitive processes as well.

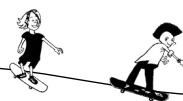
In addition to science-specific skills, students use more general thinking skills to make sense of the data and connect the observations to scientific theories (Osborne, 2015). Thinking skills include the higher order thinking skills, also frequently referred to as critical thinking (Moseley et al., 2005). Often a distinction is being made between the philosophical interpretation of critical thinking (evaluating statements and judging), and the interpretation made by psychologists who emphasize the problem-solving aspect. The latter approach is more commonly utilized in scientific inquiry (Lewis & Smith, 1993).

Thinking skills involve manipulating information that is in nature complex because it consists of more than one element and has a high level of abstraction (Flavell, Miller, & Miller, 1993). Application of thinking skills involves interpreting, analyzing, evaluating, classifying and inferring information (Moseley et al., 2005; Newmann, 1990). In correspondence with Bloom's taxonomy, thinking skills are considered to have higher levels of complexity such as analyzing and synthesizing (Bloom, 1956). Many are abundantly applied in scientific investigations. For example, when making appropriate inferences from different sources of data (Pintrich, 2002) or identifying features and patterns in data, thinking skills will predominantly underlie these particular parts of a scientific inquiry. Zohar and Dori (2003) even argue that science skills - such as formulating hypotheses or drawing conclusion - can be classified as higher order thinking skills since they share the same characteristics.

Finally, metacognitive skills are in general considered a particular type of higher order thinking skill (see for discussion Lewis & Smith, 1993). Metacognitive skills can be distinguished from general thinking skills in that metacognitive skills involve active executive control of the mental processes (Goodson, 2000) or "thinking about thinking" (Kuhn, 1999; Kuhn & Dean, 2004, p. 270). In this study, metacognitive skills refer to self-regulatory skills and include planning, monitoring and evaluating task performance (Flavell, et al., 1993; Pintrich, 2002; Schraw & Moshman, 1995).

Planning refers to selecting effective strategies and resources that will improve performance. Monitoring refers to the ability to make an estimation of how well the performance of a certain task is going. For instance, checking whether one is still on track during the task. Evaluating refers to considering the quality of the products and regulating the learning process such as reinforcing learning gains (Schraw & Moshman, 1995).

Although metacognitive skills are considered to play an important role in many types of cognitive activities (Zohar & Barzilai, 2013), these skills in particular influence the quality of the scientific inquiry process, which demands self-regulation and knowledge and use of



metacognitive strategies (Schraw et al., 2006). For instance, a student who is aware of the shortcomings of a particular inquiry may be able to improve his performance of the scientific inquiry the next time. In order to develop scientific thinking, students need to acquire metacognitive skills in order to understand, direct, monitor and evaluate their own higher order reasoning (Kuhn, 1989).

### **Learning science skills**

Scientists apply skills and knowledge in an integrated way. Still, this body of knowledge and proficiency level of skills cannot be translated directly into application in the classroom by students. Due to their lack of experience and limited mastery of strategies, skills and knowledge, students in primary education need support and scaffolding to effectively conduct a scientific inquiry. Engaging in a complex task is particularly challenging for inexperienced students since their cognitive information processing capacity is still limited (Flavell, 1992). According to the Cognitive Load Theory (CLT), working memory is limited in its capacity to process new information that contains multiple elements. Elements have to be organized in more complex units and stored in long-term memory before they can be utilized effectively (van Merriënboer & Sweller, 2005). Once this is achieved, information stored in long-term memory is accessible when needed, aiding the acquisition of science skills (Kirschner et al., 2006).

In the following subsections, several aspects about the acquisition of skills will be discussed. These aspects include explicit instruction, the influence of content knowledge and the transfer of science skills. Then, the four-component instructional design model of Van Merriënboer et al. (1992) is discussed which is specifically developed for the acquisition and integration of complex skills in whole tasks.

### **Explicit instruction**

Although there is evidence pointing to the acquisition of skills through learning by doing (Dean & Kuhn, 2007), a growing number of studies indicates that more effective learning occurs when inquiry-based learning is accompanied by explicit skill instruction or when explicit guidance is given (Alfieri, Brooks, Aldrich, & Tenenbaum, 2011; Chen & Klahr, 1999; Duschl et al., 2007, p. 271; Keselman, 2003; Khishfe & Abd-El-Khalick, 2002; Matlen & Klahr, 2013; Sweller, Kirschner, & Clark, 2007; Zohar & Ben David, 2008).

Much of what is known about the effects of explicit instruction comes from studies on the Control of Variables Strategy (CVS) (Lazonder & Egberink, 2014; Matlen & Klahr,

2013). For example, Chen and Klahr (1999) found in an intervention study with third and fourth graders that explicit instruction combined with probing questions (i.e., why they designed the investigations the way they did and what they had learned) was an effective way of learning how to apply CVS. This is in line with CLT because explicit forms of instruction put less of a burden on working memory when learning new information (Kirschner et al., 2006). Dean and Kuhn (2007) showed that in particular explicit instruction (in which students were asked to compare and identify different features of catalogues) improved students' CVS

even more when combined with practice. The positive impact of explicit instruction also seems to apply to other skills. For instance, a study by Keselman (2003) on the use of effective scientific reasoning strategies showed that students who received practice and additional explicit instruction outperformed students who were only subjected to practice.

Researchers such as Pintrich (2002) and Tanner (2012) have recommended explicit instruction of metacognitive skills to enhance task performance. Explicit instruction concerning metacognitive skills can be addressed by introducing the TASC framework (Figure 2.1). TASC stands for "Thinking Actively in a Social Context" and aims at providing students with structure to support their thinking (Wallace, Bernardelli, Molyneux, & Farrell, 2012). Students can be instructed on how to move systematically through the stages of the TASC framework while performing a task. In each stage several questions can be raised to make students aware of the need to monitor and evaluate their task execution. For instance, the students can be asked to think about what they already know about the topic of an experiment, how much information they already have, and what information they need (Wallace et al., 2012). These questions may be introduced and eventually withdrawn gradually until students are familiar with the questions and apply the metacognitive skills to each following experiment by themselves (White & Frederiksen, 2000).



**Figure 2.1**  
*TASC Framework (Wallace et al., 2012)*

### **The influence of content knowledge**

Content knowledge is in general referred to as the conceptual understanding of facts, concepts, theories and principles (Abrahams & Reiss, 2015; Ennis, 1989; French & Buchner,



1999; OECD, 2017). Research shows that content knowledge is, to a certain extent, a prerequisite for skill development (Eberbach & Crowley, 2009; Ennis, 1989). Evidence for the reciprocity of content knowledge and science skills can be derived from studies on differences in performance level between experts and novices, which shows that different levels of content knowledge can result in significant differences in skill performance (French & Buchner, 1999). Even when the level of cognitive abilities is supposed to be a limiting factor of an individual, for example for a young student, it is still possible to become an expert in a specific subject area and subsequently perform better in problem solving tasks compared to adults who know less about the subject (Glaser, 1984).

For this reason, it is important to take into account unfamiliarity with the topic of the science tasks that are included in science lessons (Pine et al., 2006). For example, making observations is largely dependent on the theoretical framework students hold and the knowledge they have on the subject (Millar & Driver, 1987). A student who has no prior knowledge at all about cells – e.g., what they look like, how big they are – is very unlikely to be able to see the same things when looking through a microscope compared to a student with extensive knowledge of cells. This is supported by studies on bird watching which demonstrated that observations only improved when basic knowledge on that subject was already developed (Eberbach & Crowley, 2009).

The potential impact of content knowledge on task performance has implications for the design of lessons aimed at the development of science skills. In designing teaching materials for science, especially for classrooms in primary education, it is important to make a clear distinction between learning objectives specific for content knowledge and learning objectives directed at skill acquisition (Hofstein & Lunetta, 2004). Although some negative interference between subject knowledge and skill development may not be entirely unavoidable, instruction needs to be constructed in such a way that skill development of individuals is not obstructed due to a lack of content knowledge. Only when students already possess or have developed skills sufficiently, more complex task may be offered in which skill application and knowledge development is integrated.

### **Transfer of skills**

More robust learning of skills has only been achieved when students are able to apply the skills in contexts other than the one in which the skills are learned. Although there is not a clear-cut definition of what different transfer distances entail (Chen & Klahr, 1999), near-transfer can generally be defined as the application of skills in tasks within a particular knowledge domain or with a common structure. Far-transfer is defined as the application of

skills in tasks in different domains or tasks with an unfamiliar structure (Strand-Cary & Klahr, 2008).

Contrary to science-specific skills, most thinking and metacognitive skills may not be exclusively linked to science tasks (Perkins & Salomon, 1989). Millar and Driver (1987) even claimed that science skills are mere “characteristics of logical thought in general” (p. 41). Evidence suggests that metacognitive and thinking skills are general abilities and can, at least partly, be applied across domains (Schraw & Moshman, 1995; Schraw, 1998). A study of Veenman, Elshout and Meijer (1997) showed that metacognitive skills such as checking the results of one’s actions and planning and monitoring while performing an activity, can be acquired in one particular domain and consecutively applied in another. Similar results were found in studies on programs aimed at development and transfer of thinking skills such as the program Cognitive Acceleration through Science Education (CASE) (Adey, Robertson, & Venville, 2002; Oliver, Venville, & Adey, 2012), and the “infusion approach” of Activating Children’s Thinking Skills (Dewey & Bento, 2009; McGuinness, Eakin, Curry, Sheehy, & Bunting, 2007).

However, achieving transfer across knowledge domains (i.e., topics) is generally difficult (Kuhn et al., 1995; Lazonder & Egberink, 2014). Studies on the Control of Variables Strategy (CVS) indicate that young students tend to fail in using the same strategies for performing tasks with different topics (cf. Chen & Klahr, 1999). To foster transfer of skills, explicit skills instruction may be particularly important. Some CVS studies have shown that explicit instruction can facilitate transfer of skills to other tasks with different topics (Klahr & Li, 2005). Making students explicitly aware of the strategies and skills that they are applying to a particular task leads to enhanced mastery which in turn may facilitate transfer (Adey & Shayer, 1993; Georgiades, 2000).

#### **Four-component instructional design**

Most of the difficulty in learning science skills is in applying them simultaneously to a scientific inquiry. In present design models, it is often assumed that, despite considerable evidence to the contrary, complex skills acquired in simple tasks will be applied spontaneously to new and more complex tasks (van Merriënboer, Clark, & de Croock, 2002, p. 40). The Four Component Instructional Design model (4C/ID), developed originally by Van Merriënboer et al. (1992), is based on research on instructional design, cognitive psychology and information processing (Vandewaetere et al., 2015). The fundamental premise of the 4C/ID-approach is that four interrelated components are essential in learning to apply and integrate skills within complex tasks: 1) whole learning tasks, 2) part-task practice, 3) supportive information, and 4) just-in-time information.



Central principle of the 4C/ID-approach is *whole-task practice*. In whole learning tasks knowledge, skills and attitude are intertwined. The underlying idea is that the whole is more than the sum of the parts, which means that it is not enough to learn to apply all skills separately, but that skills also need to be simultaneously applied to foster the interconnections between the separate skills. Whole-tasks are preferably authentic activities based on real-life scientific inquiry and are sequenced from relatively simple to complex, in terms of number of skills and interactions involved (van Merriënboer & Sweller, 2005). Research shows that acquisition of skills may be enhanced when learning tasks are sequenced from relatively simple to complex (Wu & Krajcik, 2006).

*Part-task practice* consists of smaller and simpler tasks in which parts of the whole-tasks are trained separately. By breaking down the whole scientific inquiry into smaller and manageable parts in which students can learn and practice particular skills, performance can be enhanced (Lazonder & Egberink, 2014). Part-tasks provide additional practice for a specific skill in order to reach a certain level of automaticity. In the context of science education, sequencing and combining whole learning tasks and additional part-tasks within a series of science lessons will involve careful arranging in terms of difficulty level and complexity. *Supportive information* bridges the gap between learners' prior knowledge and the knowledge necessary for task performance. It involves the use and application of rules but also includes acquiring strategies to improve performance. Finally, *just-in-time* (JIT) *information* includes the step-by-step information for the routine aspects of learning tasks. JIT information includes scaffolding, which involves providing students with support in carrying out a task which they cannot yet do on their own (Duschl et al., 2007; Wood, Bruner, & Ross, 1976). Examples of types of scaffolds are heuristics and prompts which should be withdrawn gradually as students gain proficiency in the tasks (Hohenstein & Manning, 2010; Lazonder & Harmsen, 2014; McNeill, Lizotte, Krajcik, & Marx, 2006). A final part of supportive information and JIT information includes providing students with feedback. The feedback may be given immediately or may involve stimulating students to reflect on their performance.

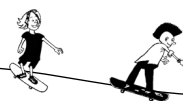
## 2.3 An instructional framework for teaching science skills: an example lesson

In this section, the first lesson which was part of the series of eight lessons for the intervention of the effect study, which showed positive effects (see chapter 4), is presented. This illustration shows how the various aspects of learning science skills as discussed above can be applied to a design for systematic skill instruction for primary science education. The principles of the 4C/ID system are used as a starting point. This involves the implementation of whole learning tasks, together with part-task practice and including scaffolding and feedback opportunities (supportive- and JIT information). The part-tasks are aimed at strengthening the underlying skills which then have to be simultaneously applied in a whole task scientific inquiry. First, additional principles which guided the instructional framework will be described. Then, the outline of the instructional framework is presented followed by a detailed description of a lesson.

### General guiding principles for teaching science skills

A generally accepted guiding principle for primary science education is the structuring of investigations by following the main steps of the empirical cycle: 1) formulating a research question, 2) formulating a hypothesis, 3) designing an experiment, 4) measuring and recording data, 5) analyzing data, and (6) formulating a conclusion. The empirical cycle reflects all aspects of a scientific inquiry that are included in most curricula as learning objectives. Because of this, most science tasks in primary education are more or less structured accordingly. Although scientific inquiry is not a linear process (NRC, 2012) and scientists merely use it as a reporting device (Kind, 1999), the subsequent activities of the empirical cycle provide a structure that is recognizable for students and their teachers. It also gives the students an understanding of how the inquiry process can be organized, which is particularly important for students in primary education who have little experience with inquiry tasks (Donovan, Bransford, & Pellegrino, 1999; White & Frederiksen, 2000).

In the series of lessons of the intervention, the principle of structuring via the steps of the empirical cycle is applied in two different ways. First, in each lesson students perform a scientific inquiry (whole task) structured identically into the six steps that represent the empirical cycle. Second, one of the steps is explicitly taught and practiced in each lesson. That is, lesson one is directed at formulating a research question, lesson two at formulating a hypothesis and so on. In the whole-task, the other steps receive less





attention because it would be too much of a burden to learn all steps in detail in one lesson. After six lessons in which all steps receive specific attention, the lessons seven and eight include tasks in which all steps are incorporated in the sense that instruction on all steps recurs, albeit less elaborately.

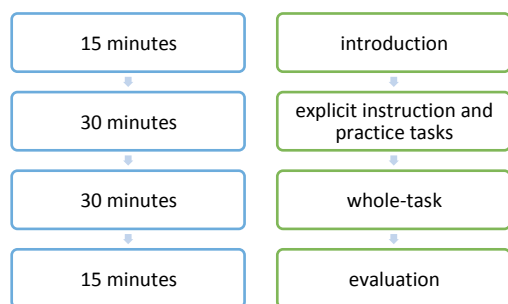
During the course of the series of lessons, on the topic of heat and temperature, the scientific inquiries gradually increase in difficulty and complexity while at the same time the explicit attention in the form of direct instruction and prompts are slowly withdrawn. At the start the teacher is fully responsible for guiding task execution, but toward the end support of the teacher is fading and the student takes over responsibility (van de Pol, Volman, & Beishuizen, 2010). For instance, the support by using TASC questions in the notebook fades away while students get used to applying the metacognitive strategies when performing scientific inquiries. In the final lesson, all skills which are practiced in previous lessons, are simultaneously applied independently and without any support to a scientific inquiry.

### **An example lesson of the instructional framework**

Here follows an elaborate description of the first lesson of the series of eight lessons to illustrate in more detail how the above described design principles were applied to a practical example. Although the intervention lessons were taught by trained teaching assistants (see chapter 4), we will refer to the teaching assistants as teachers.

In the first lesson, the students received a notebook containing information about the topic of the lesson and the tasks. They were instructed to write down their responses to the exercises and note their results of the inquiry tasks. In addition, students were given a booklet with all questions of the TASC model. The students were told to use the booklet while performing the investigations. The teachers were provided with an extensive practical guide which contained the learning objectives and detailed lesson plans. In addition, the teachers used PowerPoint presentations to guide them through the lessons. The presentations contained examples for classroom discussion, instructional prompts and explanations of the various skills.

The learning objectives for this lesson included formulating a research question, activating prior knowledge and evaluating learning gains. In this study, formulating a research question is considered primarily a science-specific skill. This implies that students have to apply procedural and declarative knowledge of what is needed for correctly formulating a research question and then apply it to the context at hand. Activating prior knowledge and evaluating learning gains are considered to be metacognitive skills which

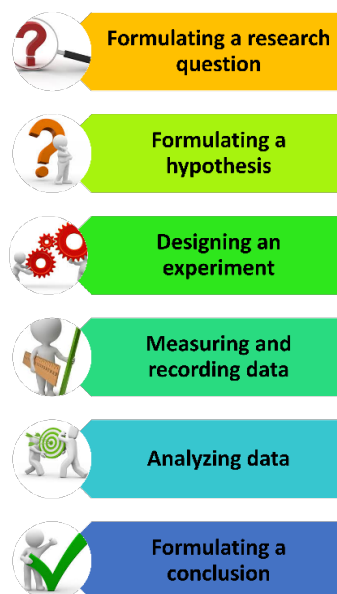


**Figure 2.2**  
*lesson outline*

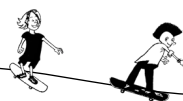
In the first 10-15 minutes of the first lesson, the TASC model was introduced. The teacher clarified the importance and goal of using TASC questions when performing an investigation. Additionally, the questions were explained and practiced in the classroom to ensure the students understood the content of the TASC questions. Then, the students were shown all steps of the empirical cycle which were printed on a poster which was in view in the classroom (Figure 2.3). This poster was present throughout the whole series of lessons. In each lesson, students were made aware of which step of the empirical cycle the particular lesson was aimed at. By doing this, the poster functioned as a scaffold when performing the scientific inquiry tasks.

In the next 30 minutes, the students received explicit, direct instruction on formulating a research question combined with part-task practice. The instruction consisted of explaining the criteria for a research question and classroom discussion about example research questions. Criteria were illustrated by means of flow chart and are based on declarative and procedural knowledge of how to formulate a proper research question (Figure 2.4). The application of this *Question Machine* (Science Education Hub Radboud University, 2016) was demonstrated by the teacher by means of a classroom discussion on a variety of example research questions. In subsequent part-task exercises, students used the Question Machine to help them to formulate a research

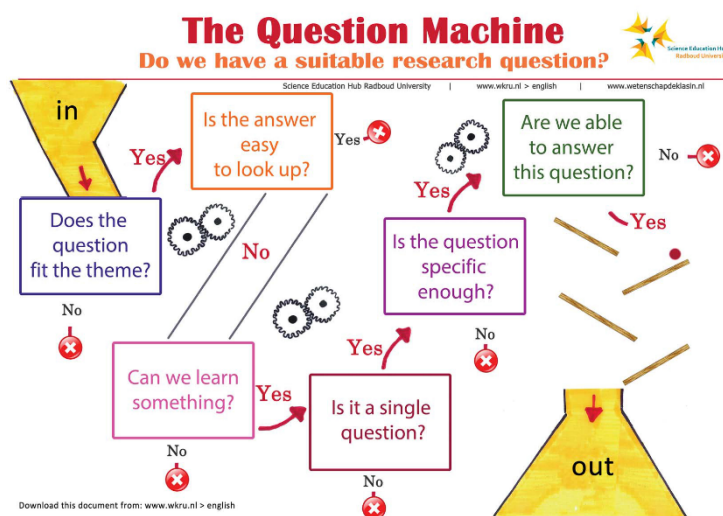
implies a different teaching approach may be necessary. Each lesson lasted 90 minutes. The first half of the lesson was spent on the explicit instruction and part-task practice of the skills as mentioned in the learning objectives. In the last 45 minutes, the whole-task - a scientific inquiry - was performed by the students and rounded off with evaluation tasks (Figure 2.2).



**Figure 2.3**  
*doorposter with the steps of the empirical cycle*



question. For instance, in the first part-task students were asked to distinguish between properly and poorly formulated research questions. Then, students had to pick two of the poorly formulated research questions and reformulate them (Table 2.1). Finally, students formulated a research question as the start of a simple scientific investigation which was introduced after students had finished the part-task exercises. By including these part-tasks, the learning of formulating a research questions is practiced in smaller parts with increasing complexity and difficulty, resulting in enhanced performance (Lazonder & Egberink, 2014). In the course of the series of lessons, students were expected to be able to formulate research questions without help. Consequently, scaffolding by means of the Question Machine was gradually withdrawn.



**Figure 2.4**  
*the Question Machine (Science Education Hub Radboud University, 2016)*

In the next 30 minutes of the lesson, students performed a relatively simple experiment in which students examined the difference in measuring temperature with their hands and with a thermometer (see Appendix A for complete description of the experiment). Students worked in groups of three. In line with the learning objectives which included formulating a research question, activating prior knowledge and evaluating learning gains, these skills were given explicit attention. The attention consisted of introducing the experiment by discussing what students already knew about the subject of temperature. The teacher made students explicitly aware of the importance of activating prior knowledge by showing

the TASC question *What do I know about this?*. Then, the teacher asked questions such as “How can you measure temperature?”, “What would you need to do to get information about the temperature outside?”, “Why does outside feels cold to one person but warm to another person?” and so on.

Throughout the experiment, illustrations of the TASC cards with discussion questions were visible for the students. Students were asked to discuss the TASC questions every time the icon of the TASC card would show up. For instance, after a short introduction of the experiment, the TASC card with the question *What is the task?* was shown. To support students in answering this question, the TASC card included additional questions, such as *What is the goal of this task?*, *What do I need to do the task?* and *Do I need*

**Table 2.1**  
*part-tasks to distinguish between properly and poorly formulated research questions and reformulate research questions*

Task 1. In the table below, you can see 9 research questions. Not all of the research questions are formulated properly. Tic the box in the column **properly formulated** if the research question is properly formulated according to the *Question Machine*. Tic the box in the column **poorly formulated** if the research question is not formulated according to the *Question Machine*. When you have finished, proceed with task 2.

research question	properly formulated	poorly formulated
1 Do all children like fries?		
2 What is the favorite food of my classmates?		
3 What causes the flu and when is the flu most common?		
4 How quickly does hot water cool in a thermos?		
5 Do my classmates learn better with or without music playing?		
6 How long does it take for an ice cube to melt?		
7 When did World War II start?		
8 Do plants grow better when you give them more water?		
9 How fast can you go from a slide and how can you slow down?		

Task 2. Choose two of the research questions of task 1 that you indicated as poorly formulated. Copy the number and the research questions. Reformulate the research questions in the right way. Use the *Question Machine*. If you are finished, check your research questions with the person sitting next to you.

Research question number ..... : .....

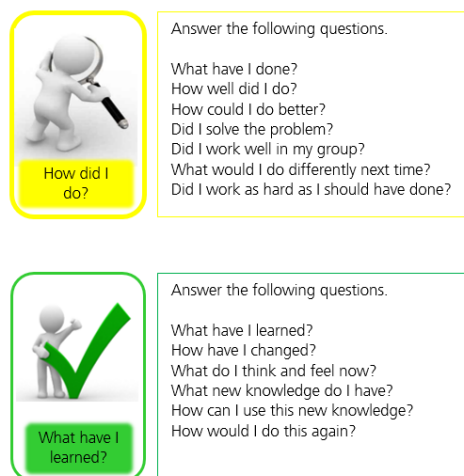
Research question number ..... : .....

*more information?* Another example included a TASC card that was presented when students were at the point of starting the actual measurements. The TASC card was aimed at the metacognitive skill of monitoring and the key question was *Let's do it and how am I doing?* The additional questions were *Am I doing this in the right way?* and *How can I monitor my progress?* In addition, students received each a small flip-over booklet including all TASC cards. Students were encouraged to take out and use this booklet every time they would perform a scientific inquiry.

During the inquiry, students were provided with information when needed such as when using a thermometer to measure the temperature of water (just-in-time information). After students had finished the inquiry, the teacher took 5 minutes to discuss the results of the inquiry and whether the research questions had been answered. Questions that were discussed included "What were the results?", "Are the results the same for everyone and what could be reason for differences?", "What is probably the best way to objectively measure temperature?". By doing this, students received explicit support in evaluating the outcomes of the inquiry.

Although the primary focus in the inquiry task was on the application of metacognitive strategies and on formulating the research question, the students went through all steps of the empirical cycle in the whole-task. However, the last steps received less attention as in each subsequent lesson one of the other steps was explicitly taught and practiced. As a result, this particular experiment was the most structured and scaffolded while in the course of the subsequent lessons the experiments became more open and more skills were used simultaneously.

In the final 15 minutes of the lesson, the students evaluated their learning gains by formulating a written answer to the following two questions: *What would you do differently the next time you perform a scientific inquiry?* and *What new knowledge do you now have about doing an inquiry?* In order to support the strategies needed for answering the questions, students were provided with two TASC cards including the additional questions (Figure 2.5). The students were asked to think about these questions first before formulating their answers to the evaluative questions.



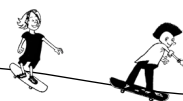
**Figure 2.5**  
*TASC cards including additional questions*

## 2.4 Discussion

In this article, an instructional approach was discussed and illustrated for teaching science skills in primary education. The general concept of science skills was operationalized in thinking skills, metacognitive skills and science-specific skills. Subsequently, the 4CD/ID-model combined with explicit instruction was applied for training primary students' science skills and providing them with extensive opportunities to implement the acquired skills in an integrated manner and in a variety of whole inquiry tasks.

Categorizing the general concept of science skills into thinking skills, metacognitive skills and science-specific skills provided the opportunity for designing and constructing teaching materials in a more systematic way. Moreover, the categorization may offer opportunities for integrating science lessons with other subjects such as language and mathematics. Findings in previous studies support the view that thinking skills and metacognitive skills are general skills which may be acquired in other school subjects as well (Dewey & Bento, 2009; Georgiades, 2000; McGuinness et al., 2007). Therefore, alignment of the curriculum for science education with the curricula of other subjects may create added value for the acquisition and transfer of thinking and metacognitive skills. In addition, since science lessons form only a small part of the overall curriculum for primary education (Martin, Mullis, Foy, & Stanco, 2012; National Academies of Sciences, Engineering, and Medicine (NASEM), 2015, p. 56), integration with other school subjects may give science education a more solid and embedded position in curricula of primary education.

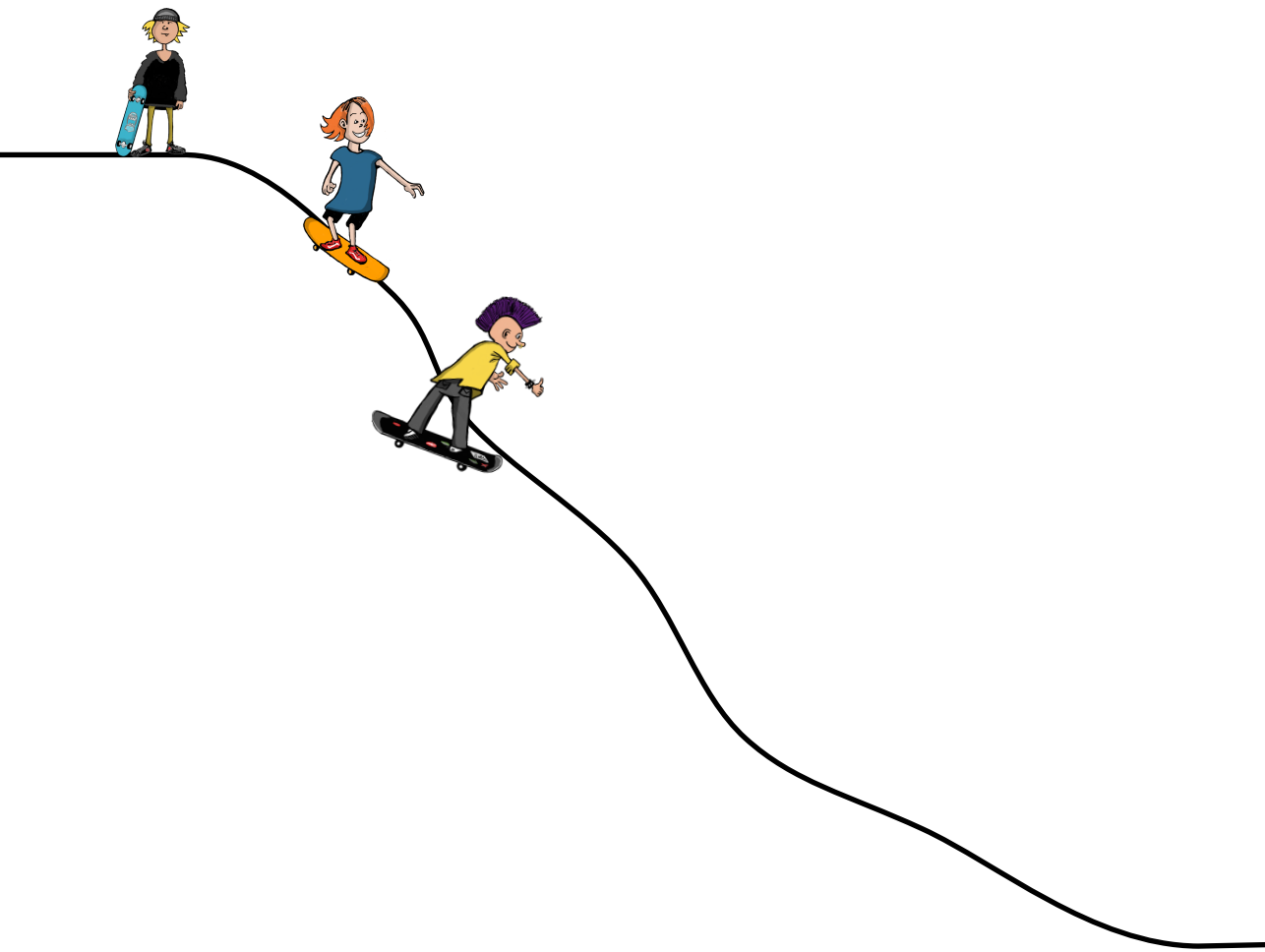
Likewise, distinguishing into three types of underlying skills offers the opportunity to align measurement instruments. In primary science education in which the underlying thinking skills, metacognitive skills and science-specific skills are explicitly taught, actual students' performance in relation to these skills should be assessed in a similar way. Science skills are generally assessed without taking into account the complexity of underlying skills that are simultaneously applied. In other words, students are assessed individually by observing the actual level of performance on a whole science task without taking into account the level of mastery of these skills underlying the complex activities. In order to establish whether a student has reached certain learning goals, it is important to construct measurement instruments directed to more distinctly assessment of the different skills. Such instruments can clarify the progress of students more accurately and may have potential to provide diagnostic information about the level of complex skill mastery.



The instructional approach was illustrated by describing a lesson used in an intervention study. This intervention study showed that the merits of the lessons were not limited to the positive effects on students' performance of the science skills. Teachers also reported that students found the lessons generally enjoyable. Most students were involved (in terms of concentration and focus on the tasks) during instruction and the assignments. In particular the investigation tasks appealed to many students. This indicates that highly structured instruction and investigations are not per se detrimental to young students' enjoyment of science lessons.

However, some critical comments were put forward by the teachers. For example, the inquiry activities took sometimes more time than was anticipated. As a result, the evaluation task was the first activity to be skipped by the teachers. As evaluating the learning gains is an important aspect of these lessons, an adjustment to the number and size of some assignments should be considered.

Actually working on challenging, meaningful and authentic small experiments stimulates students' understanding of scientific investigation. It is important for the integrated application of skills but also offers a playful way to familiarize students with the different steps of the empirical cycle (NASEM, 2015, p. 29). The students participating in the series of lessons especially enjoyed the experimenting. For the purpose of providing students with adequate scaffolding, the investigations were highly structured. When students become more skilled in performance of the scientific inquiries, more open and more interesting experiments may be preferred.





assessing students' ability  
in performing scientific inquiry :  
**instruments** for measuring  
science skills in primary education

## ABSTRACT

With the increased attention on the implementation of inquiry activities in primary science classrooms, a growing interest has emerged in assessing students' science skills. Research has thus far been concerned with the limitations and advantages of different test formats to assess students' science skills. This study explores the construction of different instruments for measuring science skills by categorizing items systematically on three subskill levels (science-specific, thinking, metacognition) as well as on different steps of the empirical cycle. The study included 128 5th and 6th grade students from seven primary schools in the Netherlands. Seven measures were used: a paper-and-pencil test, three performance assessments, two metacognitive self-report tests and a test used as an indication of general cognitive ability. Reliabilities of all tests indicate sufficient internal consistency. Positive correlations between the paper-and-pencil test and the three performance assessments show that the different tests measure a common core of similar skills thus providing evidence for convergent validity. Results also show that students' ability to perform scientific inquiry is significantly related to general cognitive ability. No relationship was found between the measure of general metacognitive ability and either the paper-and-pencil test or the three performance assessments. By contrast, the metacognitive self-report test constructed to obtain information about the application of metacognitive abilities in performing scientific inquiry, shows significant - although small - correlations with two of the performance assessments. Further explorations reveal sufficient scale reliabilities on subskill and step level. The present study shows that science skills can be measured reliably by categorizing items on subskill and step level. Additional diagnostic information can be obtained by examining mean scores on both subskill and step level. Such measures are not only suitable for assessing students' mastery of science skills but can also provide teachers with diagnostic information to adapt their instructions and foster the learning process of their students.

### Based on

Kruit, P. M., Oostdam, R. J., van den Berg, E., & Schuitema, J. A. (2018). Assessing students' ability in performing scientific inquiry: instruments for measuring science skills in primary education. *Research in Science & Technological Education*, 36 (4), 413-439.

DOI: [10.1080/02635143.2017.1421530](https://doi.org/10.1080/02635143.2017.1421530)



### 3.1 Introduction

With the increased attention toward the implementation of inquiry activities within primary science classrooms, a growing interest has emerged in assessing students' science skills, which are the skills involved in generating and validating knowledge through scientific investigations. Traditionally, most tests, whether intended for small- or large-scale assessment, have been paper-and-pencil formats consisting of multiple-choice items and/or open-ended questions (Hofstein & Lunetta, 2004). Examples of such tests are the Test of Enquiry Skills by Fraser (1980), and the test for assessing science achievement for the Third Mathematics and Science Study (TIMSS) (Martin et al., 1997).

In line with an increased understanding of how students learn, alternative assessment formats such as the use of performance assessments (Harmon et al., 1997; NRC, 2012; Shavelson, Baxter, & Pine, 1991) have been considered. In a performance assessment (PA) students perform small experiments by interacting actively with materials. PAs are regarded as "investigations that recreate to some extent the conditions under which scientists work and elicit the kind of thinking and reasoning used by scientists when they solve problems" (Shavelson, Solano-Flores, & Ruiz-Primo, 1998, p. 172).

Research has been concerned with the limitations and advantages of the different test formats. A paper-and-pencil test (PPT) can be administered easily, rated reliably and students are familiar with the format (Harlen, 1991). The major disadvantages are that a PPT lacks authenticity (Shavelson et al., 1991) or, in other words, the assessment does not reflect the activities of a real-life inquiry (Davey et al., 2015), and may be influenced considerably by reading ability (Harlen, 1991). While PAs are considered more authentic (Ennis, 1993; Davey et al., 2015) they are also more cost and labor-intensive to administer. Due to the open format, reliable rating is complicated (Davey et al., 2015) and students are often not familiarized with this test format which may negatively influence test performance (Kind, 1999).

Prior research shows that different levels of content knowledge - defined by OECD (2017, p. 74) as "knowledge of the facts, concepts, ideas and theories about the natural world that science has established" - may affect test performance as well (Eberbach & Crowley, 2009; Harlen, 1991; Roberts & Gott, 2006;). Content knowledge may have more influence on a PA than a PPT because a PA is designed around one science topic of which individual students may or may not possess prior knowledge, while a PPT contains questions about several topics. Different strategies have been used to mitigate for the content dependency of items. For example, the TIMSS 2015 Science Framework (Jones,

Wheeler, & Centurino, 2013) attempted to minimize the influence of content knowledge by assessing science skills using content where it was necessary to reason with the concepts. The Next Generation Science Standards specifically integrated content knowledge and skills in the goals for the “practices”. The concept of practices is used to integrate the science process skills and content knowledge to “emphasize that engaging in scientific investigation requires not only skill but also knowledge that is specific to each practice” (NRC, 2012, p. 30). The Assessment of Performance Unit (APU) controlled for content knowledge by minimizing the amount of content in assessments (Harlen, 1986). In the STAR (Science Teachers' Action Research) project in the UK, skills were assessed using multiple items relating back to one theme (Harlen, 1991) which is similar to a PA in which all items refer to one particular context.

Research that focuses on measuring science skills in both primary and secondary education has not only shown small correlations between PPTs and PAs (Baxter et al., 1992; Baxter & Shavelson, 1994; Hammann et al., 2008; Lawrenz, Huffman, & Welch, 2001; Roberts & Gott, 2006) but also between PAs designed to measure the same science skills (Gott & Duggan, 2002; Pine et al., 2006). These small correlations between the same and different test formats have not only been attributed to differences in students' content knowledge (Gott & Duggan, 2002; Shavelson et al., 1991), but also to inconsistencies in rating and occasion sampling variability. Occasion sampling variability occurs when students perform the same task differently on different occasions (Ruiz-Primo, Baxter, & Shavelson, 1993).

The lack of convergence between different tests intending to measure the same science skills suggests at the same time that underlying cognitive demands may not always be equally evoked (Messick, 1994; Millar & Driver, 1987; Shavelson et al., 1991). Research shows that, for example, correlations between measures of science skills and general cognitive ability in grade 9 vary from small (Song & Black, 1992; Tamir, 1988) to large (Baxter et al., 1992; Lawson, 1989) indicating that certain components of science tests may be related more to general cognitive ability and less to skills specific for science (Gott & Duggan, 2002; Pine et al., 2006; Roberts & Gott, 2006).

Of major concern in this regard is that science skills are a rather “ill-defined domain” (Gobert & Koedinger, 2011). Science skills - also referred to with terms such as “science process skills” or “investigation skills” (Harlen & Qualter, 2009) - usually indicate a wide variety of activities related to planning and conducting investigations and interpreting results (Alonzo & Aschbacher, 2004; Gott & Duggan, 1995; Harlen & Qualter, 2009). Abrahams and Reiss (2015) make an additional distinction between process skills such as



planning, predicting, and experimenting, and practical skills which are more specific such as handling a microscope.

Science skills are generally defined based on the activities in which scientists engage during authentic research (Lederman & Lederman, 2014). In the framework for K-12 science education, scientific inquiry is represented by three domains of activities: investigating, developing explanations and solutions and evaluating data as evidence for the proposed theories and models (NRC, 2012). The NRC emphasizes that students should learn about what scientists do when designing and carrying out their own inquiries. However, for assessing science skills, it is necessary to more accurately define the cognitive demands underlying the inquiry activities. In this context, Osborne (2014) argues that part of the problem lies in the focus that educators and teachers put on only the practical aspects of scientific inquiry which applies to both primary (Roth, 2014) and secondary education. This limited operationalization of science skills results in ignoring the wide variety of cognitive abilities called upon in scientific investigations. For instance, different abilities are employed when handling a microscope than when identifying patterns in data. Consequently, science skills are frequently assessed using tests that are not systematically constructed and based upon a clear operationalization of cognitive demands which underlie scientists' actual activities. Furthermore, tests often emphasize the practical side of inquiry such as controlling variables. For systematic test construction, different types of the underlying skills need to be distinguished, identified (Sternberg, 1985), and systematically included in test designs.

The aim of the present study is to explore to what extent structuring assessments by distinguishing between underlying skills will improve convergence between tests, attain more validity by including all aspects of inquiry, and offer the possibility of obtaining diagnostic information on students' performance. To this end, each activity performed in a scientific inquiry was classified by determining which of the following skills primarily underlies the activity: science-specific skills, thinking skills or metacognitive skills.

Science-specific skills refer to the ability to apply procedural and declarative knowledge for correctly setting up and conducting a scientific experiment (Gott & Murphy, 1987). These skills can be classified as lower order thinking (Newmann, 1990) or reproductive thinking (Maier cited in Lewis & Smith, 1993), and are characterized by knowledge recall, comprehension, the routine employment of rules and simple application (Goodson, 2000). Students performing a scientific inquiry are required to recall the facts and rules about how to conduct scientific experiments, such as identifying and controlling for variables, observing and measuring and using simple measurement devices. They must then use and apply this knowledge to - for example - select the appropriate procedures and

organize the data into tables (Gott & Murphy, 1987; OECD, 2017). Science-specific inquiry skills defined as such include the practical skills as discussed by Abrahams and Reiss (2015) but they pertain to cognitive processes as well.

In addition to the above-described science-specific skills, students apply more general thinking skills to make sense of the data and connect the observations to scientific theories (Osborne, 2015). Thinking skills include the higher order thinking skills, also frequently referred to as critical thinking (Moseley et al., 2005). A distinction is often made between the philosophical interpretation of critical thinking (evaluating statements and judging) and the interpretation made by psychologists who emphasize the problem-solving aspect. The latter approach is more commonly utilized in scientific inquiry (Lewis & Smith, 1993).

Thinking skills involve manipulating information that is in nature complex because it consists of more than one element and has a high level of abstraction (Flavell, Miller, & Miller, 1993). Concepts and rules are put together and applied to a new situation. The application of thinking skills involves interpreting, analyzing, evaluating, classifying and inferring information (Moseley et al., 2005; Newmann, 1990). In accordance with Bloom's taxonomy, thinking skills such as analyzing and synthesizing are considered to have higher levels of complexity (Bloom, 1956). Many of these thinking skills are abundantly applied in scientific investigations. For example, when making appropriate inferences from different sources of data (Pintrich, 2002) or when identifying features and patterns in data, thinking skills will predominantly underlie these particular aspects of a scientific inquiry. Zohar and Dori (2003) even argue that science skills such as formulating hypotheses or drawing conclusions can be classified as higher order thinking skills since they have the same characteristics.

Metacognitive skills are in general considered to be a particular type of higher order thinking skill (see for discussion Lewis & Smith, 1993). What distinguishes metacognitive skills from general thinking skills is that they involve active executive control of the mental processes (Goodson, 2000) or "thinking about thinking" (Kuhn, 1999; Kuhn & Dean, 2004, p. 270). In this study, metacognitive skills refer to self-regulatory skills and include planning, monitoring, and evaluating task performance (Flavell et al., 1993; Pintrich, 2002; Schraw & Moshman, 1995). Planning refers to selecting effective strategies and resources that will improve performance. Monitoring concerns being aware of comprehension and task performance. For instance, checking to see whether one is still on track during the task. Evaluating refers to the judging the quality of the products and the process of achieving the goal, such as reflecting on what one could have done differently for better results (Schraw & Moshman, 1995). Although metacognitive skills are considered to play an



important role in many types of cognitive activities (Zohar & Barzilai, 2013), these skills influence the quality of the scientific inquiry process, which in particular demands self-regulation and knowledge and use of metacognitive strategies (Schraw, Crippen, & Hartley, 2006). For instance, a student who is aware of the shortcomings of a particular inquiry may be able to improve his or her performance in a subsequent scientific inquiry. To become a scientific thinker, students need to acquire metacognitive skills in order to understand, direct, monitor and evaluate their own higher order reasoning (Kuhn, 1989).

To further reduce the lack of convergence between tests, the following main activities ('steps') within the empirical cycle were used as a general blueprint for test construction: (1) formulating a research question, (2) designing an experiment, (3) formulating a hypothesis, (4) measuring and recording data, (5) analyzing data, (6) formulating a conclusion and (7) evaluating. Although scientists do not move linearly through the three domains of activity (NRC, 2012) and merely use it as a reporting device (Kind, 1999), the empirical cycle reflects all of the aspects of a scientific inquiry which are included as learning objectives in most curricula. Deploying the empirical cycle as a blueprint for test construction ensures that the same activities of scientific inquiry are included in each test and thus ensures construct validity (Solano-Flores, Javanovic, Shavelson, & Bachman, 1999). Furthermore, systematically assembling these activities within tests may provide a useful scaffold, especially for students in primary education who have little inquiry experience (Donovan, Bransford, & Pellegrino, 1999; cf. White & Frederiksen, 2000).

In summary, we explored the construction of different instruments for measuring science skills in grades 5 and 6 of primary education. In contrast to current measures, we aimed for a systematic construction of instruments by assigning items to the different activities of the empirical cycle and by categorizing them in relation to science-specific skills, thinking skills and metacognitive skills. In this way, we ensured that tests contained the major aspects of scientific inquiry while doing justice to the different cognitive demands which are often overlooked by teachers when assessing science skills (Osborne, 2014). Although the underlying skills are not measured directly because the tests aim only to measure the activities performed in a scientific inquiry, it is still possible to obtain a reflection of students' mastery of science-specific skills as well as thinking and metacognitive skills. In addition, the influence of prior content knowledge is controlled for as much as possible.

Furthermore, we examined to what extent the different instruments measure science skills in relation to general cognitive ability and also whether the categorization of items on underlying skill (subskill) level (science-specific, thinking and metacognition) and

step level of the empirical cycle might provide additional diagnostic information. Hence, the following research questions were addressed:

1. Can students' ability in performing scientific inquiry be measured in a reliable manner?
2. To what extent is the measurement of students' ability in performing scientific inquiry related to their general cognitive ability?
3. Can students' ability in performing scientific inquiry be validly measured by means of different assessment instruments?
4. To what extent do measurements on subskill and step level provide additional diagnostic information to the overall measurement of students' ability in performing scientific inquiry?





## 3.2 Method

### Participants

All measuring instruments were administered to 128 students (55% female, 45% male) with a mean age of 11.4 ( $SD = .64$ ) from seven primary schools in the Netherlands. Seventy-five students (59%) were in grade 5 and 53 (41%) were in grade 6. Some students had prior experience with scientific investigations because of lessons provided within the regular school science curriculum. Science skills had not previously been assessed by means of a PPT or a PA at these schools.

### Measuring instruments

#### Paper-and-pencil test

Items for the PPT were selected from large-scale assessments and other sources (e.g., SOLpass.org) based on the following criteria. Construct validity was maintained by assigning items to the different steps of the empirical cycle and by categorizing them in relation to the primary subskill which underlies the particular activity performed in the item (Table 3.1). For instance, one of the items contained a short description of an experiment and the data measured. The students were asked to draw a graph of these data. This item was categorized as a science-specific skill and simultaneously assigned to the step of “recording and organizing data”. The PPT contained items that measured thinking and science-specific skills (see Appendix B for some example items). Items on metacognition such as choosing alternative strategies or evaluating learning gains were not included because answers are based on self-assessments and cannot simply be scored as correct or incorrect (Shavelson, Carey, & Webb, 1990). Limited test time available at schools resulted in balancing time-consuming open-ended questions, such as providing an explanation or making a graph, with more time-efficient multiple choice questions.

To ensure content validity, university lecturers in the fields of biology and physics education assessed all items for correct representation of the phenomena. In addition, these content experts checked that items were correctly classified to subskill and step level. Next, primary school teachers verified the formulation of the items and the content familiarity for grades 5 and 6 students. As a result, minor adjustments were made, such as substituting relatively unfamiliar words with more commonly used words. Finally, a small group of five students of similar age were asked to complete the initial draft of the PPT and to explain their answers in an informal interview to check comprehensibility of content and

language. As a result, some items were revised or deleted. For example, one item required students to look at a drawing of a cat and interpret its mood. However, it turned out that only students who owned a cat were able to interpret the cat's behavior as shown in the drawing. This item was therefore deleted.

The preliminary version of the PPT was piloted in two rounds with, respectively, 117 and 158 students from grades 5 and 6. Based on the results of these pilot studies items with item total correlations below .15 were deleted, resulting in a final version with 46 items (Table 3.1).

A scoring model was developed for assessing answers to the open-ended questions. To ensure scoring validity, possible answers were first formulated by content experts and then fine-tuned based on students' answers. Criteria for awarding points were based on the level of complexity of the answers, meaning that the more elements the answer needed, the more points could be awarded. For instance, drawing a graph involves (a) labeling the axes, (b) putting the data points in the right place, and (c) drawing a line of best-fit (see Appendix C for an example of a scoring model).

For administration purposes, the items of the final version of the PPT were divided into two test booklets based on an optimal split half. Each test booklet contained 18 multiple choice and 5 open-ended items. Administration of each booklet in the present study took about 45 minutes.

**Table 3.1**  
*distribution of multiple choice and open-ended items in the PPT, classified to subskill level*

item description	number of items	multiple choice	open-ended
Thinking: formulate hypothesis	5	3	2
Thinking: control variables	4	4	-
Thinking: identify features, patterns, contradictions in data	6	3	3
Thinking: make inferences informed by evidence and reason	6	5	1
Thinking: relate conclusion to hypothesis/draw conclusion	7	7	-
Science-specific: formulate research question	6	6	-
Science-specific: observe/measure correctly	6	6	-
Science-specific: organize data	6	2	4
Total number of items for thinking skills	28		
Total number of items for science-specific skills	18		



### Performance assessments

Based on PAs in previous large-scale studies for grades 5 and 6, three tasks were developed with topics suitable for students of this age: *Skateboard*, *Bungee Jump*, and *Hot Chocolate*. Skateboard was based on the PA Rolling Down Hill (Ahlbrand, Green, Grogg, Gould, & Winnett, 1993). Bungee Jump and Hot Chocolate were based on task formats in TIMSS (Martin et al., 1997).

All three PAs concern comparative investigations: students are asked to examine the relationship between two variables (Shavelson et al., 1998). In Skateboard, students must roll a marble (the “skateboard”) down a ruler (the “hill”) to examine the relationship between the distance of the marble on the ruler (slope) and the distance the marble covers at the end of the ruler while pushing a paper wedge forward. Comparable investigations must be performed in Bungee Jump (students examine how the length of a rubber band may change by hanging additional weights) and Hot Chocolate (relationship between the amount of hot water and the rate of cooling).

Each PA is constructed according to the same template following the various activities (steps) of the empirical cycle (Table 3.2). Subsequently, the different activities are categorized as “science-specific”, “thinking”, or “metacognitive”. As mentioned before, this categorization is based on the prevailing skill of a particular activity. For instance, the activity of planning an experiment is related to describing the setup of the investigation and the way in which results will be noted. This activity is therefore categorized as science-specific, although it requires thinking and metacognition as well.

To reach a high quality of content validity, the university lecturers in the field of biology and physics education assessed all items regarding clarity of formulation and the main subskill and activity to be measured. According to Clauser (2000), it should be taken into consideration that subject-matter experts may be too focused on details not appropriate for primary school students. Therefore, primary school teachers were also requested to assess all items on the same characteristics. As a result, minor adjustments were made. For example, in the empirical cycle, formulating a research question is usually followed by formulating a hypothesis and then planning the experiment. However, for primary school students formulating a hypothesis *after* planning the experiment provides students with additional scaffolding.

Preliminary versions of all three PAs were piloted with 70 grades 5 and 6 students. Based on the outcomes several adjustments were made regarding the formulation of instructions, questions and task structure.

Simultaneously, a scoring rubric was developed for each PA. Scoring validity was attained in the following ways (Kane, Crooks, & Cohen, 1999). Criteria for awarding points

were expressed as detailed descriptions of the elements that should be included in students' answers. University teachers as content experts assessed the criteria for awarding points to the different levels of proficiency of possible answers, meaning that when the answer contains more elements, a higher level of proficiency is reached. Depending on the number of elements more points are awarded (Table 3.2). In addition, teachers considered whether the criteria were feasible for grades 5 and 6 students. Students' responses obtained from the pilots were used to fine-tune the scoring criteria and examples were added to illustrate the different levels of proficiency (see Appendices C and D for examples of a scoring rubric).

As shown in Table 3.2, each PA contained 14 quantifiable items to be completed in about 45 minutes. Scoring of items was based on students' answers which were written down in notebooks. The rationale behind using students' answers is that in authentic inquiry in which all activities are performed, these written responses can be interpreted as a summary of the actual scientific investigation (Kind, 1999). An important advantage of using notebooks is that it makes it possible to score and analyze the students' work after the event has occurred (Schilling et al., 1990). Furthermore, scoring based on written answers has proven to be a good alternative for real-time observation (Ruiz-Primo et al., 1993; Solano-Flores et al., 1999) and is assumed to provide a valid indication of the students' potential performance in real life inquiry (Harmon et al., 1997).

Raters were thoroughly trained to interpret the criteria as intended and to award points to students' answers. During training sessions scoring rubrics were fine-tuned with additional examples of possible answers.



**Table 3.2*****blueprint of the performance assessments with items classified to subskill and step level***

item	description of activities	step level	subskill level	score
1	Students formulate their own research question	Research question	Science-specific	0-1-2
2	Students design experiment: Description of experimental setup Description of how results will be noted	Design	Science-specific	0-1-2-3 0-1-2
3	Students formulate hypothesis	Hypothesis	Thinking	0-1-2
4	Students note their results in a table students make themselves	Measure & record	Science-specific	0-1-2-3
5	Students make a graph of the data they gathered: Axes Line graph	Measure & record	Science-specific	0-1-2 0-1-2
6	Students interpret the results by relating two variables	Analyze	Thinking	0-1-2
7	Students extrapolate the results	Analyze	Thinking	0-1-2
8	Students draw a conclusion about relationship	Conclusion	Thinking	0-1-2
9	Students formulate support for their conclusion	Conclusion	Thinking	0-1-2
10	Students relate the hypothesis to the conclusion	Conclusion	Thinking	0-1-2
11	Students identify differences between plan and execution of experiment and explain reason(s) of differences or in absence of differences, give suggestions to improve the experiment	Evaluate	Metacognitive	0-1-2
12	Students give suggestions to extend the experiment	Evaluate	Metacognitive	0-1-2
13	Students draw a conclusion related to the context	Conclusion	Thinking	0-1-2
14	Students formulate their learning gains about inquiry	Evaluate	Metacognitive	0-1-2
maximum score				34

### Metacognitive self-report tests

Two metacognitive self-report tests were used. The first test was based on the Junior Metacognitive Awareness Inventory (Jr. MAI), a self-report inventory for grades 3-5 developed by Sperling, Howard, Miller, & Murphy (2002). Jr. MAI has been used in other research and proven to be a valid measure for metacognition (see Sperling et al., 2002 for discussion). Moreover, Jr. MAI has been validated specifically for measuring metacognition in young students and is therefore appropriate for our purposes. The test is easy to administer and score.

Jr. MAI consists of 12 items with a three-choice response (never, sometimes, or always). Of these 12 items, 6 items evaluate metacognitive knowledge. For example: *I know when I understand something*. The other 6 items are directed at assessing regulation of cognition. For instance, *I think about what I need to learn before I start working*. For the present study, the 12 items were translated into Dutch by the researcher, an educational scientist and a primary school teacher. The translations were then translated back into English and compared with the original Jr. MAI of Sperling et al. (2002).

The second metacognitive self-report test - Science Meta Test (SMT) - was designed to measure metacognitive self-regulatory skills, including orientation/planning, monitoring and evaluation (Schraw & Moshman, 1995). In contrast to the more general Jr. MAI, items were constructed specifically to obtain information about the extent to which metacognitive skills are applied in the PAs. For example: *While doing measurements, I continued to verify that I was following my plan*. Submitting the items to a small sample of students showed that no reading or comprehension problems occurred. The final version of the SMT consisted of 13 items with a three-point scale (not, a little, a lot).

### Combined Cito scores

Most primary schools participate in a semi-annual assessment of The National Institute for Educational Testing and Assessment (Stichting Cito Instituut voor Toetsontwikkeling) to monitor students' achievement. Scores are used to advise students for continuing education. Since Cito scores of Reading comprehension and Arithmetic/mathematics significantly correlate with other tests measuring general ability, Cito scores can be considered a valid indication of general cognitive ability (Bartels, Rietveld, van Baal, & Boomsma, 2002; De Jong & Das-Smaal, 1995; te Nijenhuis, Tolboom, Resing, & Bleichrodt, 2004). Because scores on these reliable standardized tests were available, a separate cognitive ability test - which would have required additional time and effort for the schools and students - was not administered.



Ability is expressed by different levels which indicate the actual performance level of a student compared to a norm group (A=upper 25% of all children, B=25% above mean, C=25% below mean, D=next 15% below C, E=lowest 10%). As a result of the norm-based interpretation, students' test scores can be compared within and between grades. For Reading comprehension and Arithmetic/ mathematics both reliability scores (indicated by Accuracy of Measurement) are high,  $>.87$  and  $>.95$  respectively for grades 5 and 6 (Janssen, Verhelst, Engelen, & Scheltens, 2010; Weekers, Groenen, Kleintjes, & Feenstra, 2011). For this study, the mid-term tests scores were transformed into a five-point scale (A=5 to E=1). A combined Cito score (CCS) was established by summing the scores of both tests.

### **Administration procedure**

Research assistants administered the PPT to all 128 students in a classroom setting and the PAs individually in groups of four to a maximum of eight students. Each research assistant received extensive training and followed detailed protocols for test administration.

Tests were administered to all students on two separate occasions with a time interval of 8-10 weeks. On each occasion tests were administered in the same order: first one split half of the PPT followed by a performance assessment. Skateboard was administered on the first occasion and the other two PAs on the second occasion. To control for sequencing effects, administration of the PAs on the second occasion was randomly rotated. The two metacognitive self-report tests were administered on the second occasion after Bungee Jump.

### **Scoring procedure**

All handwritten answers to open-ended questions for the PPT and PAs were transcribed to typed text. By doing this, raters were not able to recognize or be influenced by handwriting.

Three raters, all master students, received separate training for the scoring of open-ended questions in the PPT and PAs. Before every training session, raters were provided with the test material, the scoring rubrics and a set of answers of students reflecting various performance levels. Interrater reliability was estimated by determining intraclass correlation (*ICC*, two-way random, absolute agreement) for each rating session on a random sample of an average of 12% of the scores. To avoid bias, raters were instructed to score one item for all students before moving on to the next item. In this way, more sensitivity to different performance levels regarding a particular item was achieved. Depending on the

interrater agreement reached, additional discussion of rating differences was initiated. After establishing satisfactory interrater reliability (varying from .71 to .92, single measures ICC) administered tests were randomly distributed to be scored by individual raters. On average, the rating process took 10 minutes per student for the PPT and 20 minutes per student for a PA.

### **Method of analysis**

The dataset contained the scores on all measures taken of a total of 128 primary school students. Variables were examined for accuracy of data entry, missing values and distributions. There were less than 5% missing values on the variables of the metacognitive self-report tests and the Cito tests. Little's MCAR test was not significant indicating that no identifiable pattern exists for the missing data ( $\chi^2 = 1596.125$ ,  $df = 1593$ ,  $p = .47$ ). EM imputation was performed for missing items of the metacognitive self-report tests. Imputation for missing items of the Cito tests was not possible because only the overall test score was available. All underlying assumptions (e.g., normality) were met.

Overall scores and reliabilities were calculated for all measures. In addition, scores and reliabilities on subskill and step level were calculated for the PPT and PAs. Average item scores were calculated for Jr. MAI and the SMT. Pearson zero-order and partial correlations were calculated to examine discriminant and convergent validity.





### 3.3 Results

#### Descriptive statistics

Table 3.3 presents the means and standard deviations for all measures. Both PPT and PAs show normal distributions of scores, indicating that no floor or ceiling effects occur. All PAs show relatively low means indicating a high difficulty level with an average of 31% of the highest score possible. Four students had a score of 0 for Skateboard and for Bungee Jump, and for Hot Chocolate, only two students had a score of 0. There is therefore no indication of a substantial floor effect. A repeated-measures ANOVA revealed significant differences between the three PAs (Wilks' lambda = .921,  $F(2, 126) = 5.40$ ,  $p = .006$ ,  $\eta_p^2 = .079$ ). Pairwise comparisons demonstrated differences between Skateboard and Bungee Jump (mean difference 1.242, 95% CI [.191, 2.294],  $p = .015$ ) and between Bungee Jump and Hot Chocolate (mean difference .977, 95% CI [.102, 1.851],  $p = .023$ ). When interpreting scores as a measure of difficulty, these differences indicate that Bungee Jump is somewhat easier than the other two PAs.

**Table 3.3**  
*means and standard deviations for all measures*

	max score	min	max	M	SD
PPT	60	11	49	31.12	8.67
PAs					
Skateboard	34	0	23	10.07	5.56
Bungee Jump	34	0	24	11.31	5.09
Hot Chocolate	34	0	21	10.34	4.88
Jr. MAI	3	1.50	2.75	2.32	.25
SMT	3	1.23	3.00	2.16	.31
CCS	10	2	10	6.92	2.23

*Note:* max score = maximum score possible of test  
min = minimum score of student  
max = maximum score of student

Scores (indicated by average item scores) on Jr. MAI are relatively high, while scores on the SMT are more evenly spread. The mean of CCS shows that students perform around average. For the PPT, Bungee Jump and Hot Chocolate girls outperformed boys. However, results show that the boys had significant higher scores for Jr. MAI. Except for the PPT on

which students in grade 6 scored higher than grade 5 students, there were no differences in scores between grades.

### Test reliabilities

In order to answer the first research question, test reliabilities were calculated. Cronbach's  $\alpha$  coefficient for the PPT can be considered good (Table 3.4). Deleting items would not substantially improve the reliability coefficient. The  $\alpha$ -coefficients for the three PAs as well as the metacognitive self-report tests indicate sufficient internal consistency.

**Table 3.4**  
*reliability coefficients of all measures (Cronbach's  $\alpha$ )*

	$\alpha$
PPT	.82
PAs	
Skateboard	.72
Bungee Jump	.67
Hot Chocolate	.69
Jr. MAI	.62
SMT	.66

*Note: see method section for reliability of the CCS*

### Relationship between science measures and combined Cito score (CCS)

To examine discriminant validity (research question 2), interdependency between science measures and CCS was explored. Medium to large correlations (Cohen, 1988) were found between CCS and respectively the PPT and PAs (Table 3.5). No significant correlations were found between CCS and the two metacognitive self-report tests.

### Relationship between science measures

To find evidence of convergent validity (research question 3), we explored to what extent the overall scores for the different science measures correlate. Because findings show that the sciences measures are related to the combined Cito score (Table 3.5) correlations were controlled for the scores on this test.



**Table 3.5**

**correlations (Pearson's  $r$ ) between science measures and CCS as a reflection of general cognitive ability ( $df = 121$ )**

	CCS
PPT	.67*
PAs	
Skateboard	.51*
Bungee Jump	.55*
Hot Chocolate	.42*
Jr. MAI	.04
SMT	-.01

\* correlations are significant at  $p < .001$  (2-tailed)

Medium to large significant positive correlations were found between the PPT and all three PAs (Table 3.6). Tests for comparing dependent correlations measured on the same subjects (Steiger, 1980) revealed a significant difference between Bungee Jump and Hot Chocolate and between Bungee Jump and Skateboard ( $Z = 1.96$ ,  $p = .05$ ). The average correlation between the three PAs is higher ( $r = .48$ ) than between the PPT and the PAs ( $r = .39$ ), indicating that the PAs tap into somewhat different skills than the PPT. Still, the medium to large correlations between the PPT and the three PAs reinforce that both test formats measure a common core of similar skills, other than that of general cognitive ability alone.

**Table 3.6**

**correlations (Pearson's  $r$ ) between science measures controlling for CCS ( $df = 120$ )**

	1	2	3	4	5
1. PPT					
PAs					
2. Skateboard	.43*				
3. Bungee Jump	.34*	.42*			
4. Hot Chocolate	.40*	.46*	.57*		
5. Jr. MAI	-.11	.04	.04	.05	
6. SMT	-.02	.12	.20**	.19***	.65*

\* correlations are significant at  $p < .001$  (2-tailed)

\*\*  $p = .029$

\*\*\*  $p = .038$

No significant correlations occurred between Jr. MAI and the PAs. These results may indicate that the general metacognitive skills measured by the Jr. MAI were not reflected by the PAs. An alternative explanation may be that the Jr. MAI lacked the sensitivity to measure metacognitive skills.

The SMT, designed specifically to obtain information about the extent to which metacognitive skills are applied in the PAs, correlated significantly with Bungee Jump and Hot Chocolate but not with Skateboard. Although correlations are small, this might indicate that the metacognitive skills measured in the PAs may be of a more task-specific nature than those obtained by measuring general metacognitive skills.

### **Additional diagnostic information on subskill and step level**

#### Descriptive statistics

In order to answer research question 4, we explored whether an analysis on subskill and step level provided additional diagnostic information about students' performance levels. Each item in the assessments was assigned to the subskill that most underlaid the concerning activity. Then, scores of each scale were obtained, which reflected the main underlying skill applied to that particular cluster of activities. To explore how students performed in the particular aspects of the empirical cycle, scores per step level were also calculated.

**Table 3.7**  
*means and standard deviations of standardized scores (0-10) on subskill and step level*

	PPT		PA		total	
	M	SD	M	SD	M	SD
subskill						
Thinking	5.63	1.52	3.00	1.53	4.14	1.33
Science	4.67	1.73	3.26	1.59	3.83	1.49
Meta	-	-	2.99	1.54	2.99	1.54
step empirical cycle						
Research question	7.73	2.28	4.71	2.79	6.22	2.12
Design experiment	3.95	3.24	2.76	1.60	3.01	1.53
Hypothesis	6.22	2.20	4.60	2.52	5.47	1.90
Measure and record	3.84	1.84	3.21	1.98	3.53	1.69
Analyze	6.21	1.64	2.76	2.02	4.62	1.51
Conclusion	4.88	2.13	2.73	1.59	3.21	1.43
Evaluation	-	-	2.99	1.54	2.99	1.54



In Table 3.7 the descriptive statistics on subskill and step level are given for all measures. To facilitate comparison between tests, scores were converted to standardized scales between 0 and 10. Means and standard deviations show that on subskill level scores are somewhat low but similar within tests. Scores on step level are more evenly spread within tests, indicating differences between steps in terms of difficulty. Examining the scores for the PPT shows, for instance, that designing an experiment (3.95) seems to be more difficult than formulating a hypothesis (6.22). In general, scores on step level are higher for the PPT than for the PAs, suggesting that different test formats elicit the same skills but are applied in different ways (see also Table 3.3). For instance, formulating a research question is not the same as identifying a research question from amongst different multiple-choice options.

#### Reliabilities on subskill and step level

In Table 3.8, scale reliabilities on subskill level are presented for the PPT and the PAs. Because the three PAs are similar in respect to format, wording, number of items and structure, separate scores could be combined to obtain a reliable aggregated score. By doing so, variance caused by task effects was reduced.

**Table 3.8**

***scale reliabilities of items measuring the same subskill per tests and aggregated for the PPT, PAs, and PAs together (Cronbach's  $\alpha$ )***

	thinking	science	meta	total
PPT	.73	.69	-	.82
PAs				
Skateboard	.59	.55	.36	.72
Bungee Jump	.58	.31	.37	.67
Hot Chocolate	.53	.54	.36	.69
aggregated scores of PAs	.77	.74	.64	.86

*Note: aggregated scores represent scores for all three performance assessments as one construct*

Internal consistency specified by Cronbach's  $\alpha$  indicates coherent scales on subskill level.

In addition to presenting Cronbach's  $\alpha$  for scales on subskill level (Table 3.8), also the internal consistency on step level was investigated. Table 3.9 presents scale reliabilities on step level for the PPT and the PAs. The items of the PAs assigned to metacognition represent the evaluation step as well. Cronbach's  $\alpha$  coefficients are in general weak to moderate, indicating that ability scores on the level of the steps should be interpreted with caution.

**Table 3.9**

**reliability of the paper-and-pencil test (PPT) and the performance assessments (PA) on empirical step level indicated by Cronbach  $\alpha$**

	PPT		PA	
	number of items	$\alpha$	number of items	$\alpha$
Research question	6	.53	3	.54
Design experiment	4	.58	3	.56
Hypothesis	5	.26	3	.44
Measure and record	12	.62	6	.59
Analyze	12	.56	6	.47
Conclusion	7	.37	12	.66
Evaluation	-	-	9	.64

### Relationship with combined Cito score (CCS)

To investigate to what extent general cognitive ability influences ability on subskill level, correlations were calculated for each subskill. Large correlations were found between CCS and the subskills thinking and science-specific (Table 3.10). For metacognition, the correlation with CCS is small, indicating that items in which metacognitive skills are called upon may tap less into general cognitive ability, reflected by CCS, than do thinking and science-specific items. However, this result might also be explained by the small number of items used to measure metacognitive skills. Alternatively, a study by Veenman, Wilhelm and Beishuizen (2004) showed that in this age group, students' metacognitive skills are better able to predict learning performance than their intellectual ability. This was attributed to the fact that the tasks in the experiment were too complex for the students. The small correlation between the metacognitive items and the CCS may be attributable to a similar effect.

**Table 3.10**

**correlations (Pearson's  $r$ ) between scores on subskill level and CCS ( $df = 121$ )**

	CCS (general cognitive ability)
PPT thinking	.59*
PPT science	.61*
PA thinking	.51*
PA science	.55*
PA metacognitive	.27**

\* correlations are significant at  $p < .001$  (2-tailed)

\*\*  $p = .003$



Table 3.11 shows significant correlations between CCS and scale scores on step level. In general, correlations are medium for each step of the empirical cycle, with the exception of “Hypothesis” in the PPT and “Evaluation” in the PA, indicating that general cognitive ability reflected by CCS substantially influences performance on step level.

**Table 3.11**  
*correlations (Pearson’s  $r$ ) between scores on step level and CCS ( $df = 121$ )*

	CCS (general cognitive ability)	
	PPT	PA
Research question	.48 <sup>*</sup>	.39 <sup>*</sup>
Design experiment	.33 <sup>*</sup>	.42 <sup>*</sup>
Hypothesis	.28 <sup>**</sup>	.47 <sup>*</sup>
Measure and record	.57 <sup>*</sup>	.48 <sup>*</sup>
Analyze	.57 <sup>*</sup>	.38
Conclusion	.46 <sup>*</sup>	.42 <sup>*</sup>
Evaluation	-	.27 <sup>***</sup>

<sup>\*</sup> correlations are significant at  $p < .001$  (2-tailed)

<sup>\*\*</sup>  $p = .002$

<sup>\*\*\*</sup>  $p = .003$

### Relationship between subskills and steps of the empirical cycle

For further exploration of the relation between the subskills, correlations were calculated for the PPT and the aggregated PA-scores and controlled for by CCS (Table 3.12). The SMT did not correlate significantly with items assigned to thinking skills or to science-specific skills. However, the SMT did correlate significantly with items assigned to metacognitive

**Table 3.12**  
*correlations (Pearson’s  $r$ ) between subskills, controlled for CCS ( $df = 120$ )*

	PPT thinking	PPT science	PA thinking	PA science	PA meta	Jr. MAI
PPT thinking						
PPT science	.40 <sup>*</sup>					
PA thinking	.29 <sup>**</sup>	.20 <sup>**</sup>				
PA science	.38 <sup>*</sup>	.45 <sup>*</sup>	.45 <sup>*</sup>			
PA meta	.35 <sup>*</sup>	.17	.44 <sup>*</sup>	.28 <sup>**</sup>		
Jr. MAI	-.14	-.03	.02	.03	.11	
SMT	-.04	.01	.13	.17	.21 <sup>**</sup>	.65 <sup>*</sup>

<sup>\*</sup> correlation is significant at  $p < .001$  (2-tailed)

<sup>\*\*</sup> correlations are significant at  $p < .05$  (2-tailed)

skills, indicating that thinking and science-specific items measure other skills than do the metacognitive items.

Correlations between the different steps of the empirical cycle were calculated for the PPT and the aggregated PA scores controlling for CCS (Table 3.13).

**Table 3.13**  
*correlations (Pearson's  $r$ ) between steps of the empirical cycle, controlled for by CCS ( $df = 120$ )*

	1	2	3	4	5	6	7	8	9	10	11	12
1. PPT research question												
2. PPT design	.03											
3. PPT hypothesis	.37*	.03										
4. PPT measure & record	.30*	.14	.16									
5. PPT analyze	.27*	.10	.35*	.32*								
6. PPT conclusion	.14	.15	.27**	.25**	.47**							
7. PA research question	.22**	.12	.19**	.17	.18	.02						
8. PA design	.20**	.05	.22**	.39*	.31*	.17	.25*					
9. PA hypothesis	.06	.04	.21**	.13	.24*	.20**	.25*	.19**				
10. PA measure & record	.04	-.03	.26**	.41*	.26*	.30*	.24*	.41*	.26*			
11. PA analyze	.14	.14	.19**	.13	.21**	.15	.33*	.25*	.26*	.26*		
12. PA conclusion	.16	-.03	.14	.15	.23**	.09	.38*	.32*	.18**	.21**	.57*	
13. PA evaluation	.07	.23**	.34*	.17	.27*	.06	.16	.29*	.25*	.18**	.36*	.37*

\* correlation is significant at  $p < .001$  (2-tailed)

\*\* correlations are significant at  $p < .05$  (2-tailed)

The positive, significant correlations between all steps of the PAs and between most corresponding steps of the PPT and PAs indicate mutual cognitive demands of the activities. In contrast, correlations between steps of the PPT are more erratic. Differences may be explained by the productive application of skills required for PAs and some items in the PPT, in contrast to the more receptive way (students are asked to choose between alternative answers) skills are applied in most items of the PPT. This can be illustrated by the small correlation of .05 between the PPT and PAs concerning the activity of designing an experiment.





### 3.4 Conclusion and discussion

The present study shows that science skills can be measured reliably in grades 5 and 6. By categorizing items systematically on subskill and step level, sufficient reliabilities for the different science measures (PPT, PAs, and metacognitive self-report tests) can be obtained. The results of previous research (cf. Pine et al., 2006; Roberts & Gott, 2006), showing that students' ability to perform a scientific inquiry is significantly related to their general cognitive ability, are reaffirmed in this study provided the combined Cito scores are interpreted as a reflection of general cognitive ability. Correlations between CCS and the PPT and PAs varied between .42 and .67 indicating that - despite the fact that some overlap still exists with general cognitive ability - a different construct is being measured. This implies that the tests primarily measure skills other than general cognitive ability.

Former research gave ample evidence that convergent validity between different tests for measuring science skills is difficult to establish (cf. Hammann et al., 2008; Pine et al., 2006). This lack of convergence between tests intending to measure similar science skills suggests that items within these tests do not equally appeal to underlying cognitive abilities. As demonstrated in this study, categorization of items in relation to science-specific, thinking and metacognitive skills results in more systematic test construction and thus provides evidence for convergent validity. In addition, using the steps (activities) of the empirical cycle as a blueprint ensures that within tests all aspects of scientific inquiry are incorporated (Messick, 1994; Mislevy & Haertel, 2006). The added value of this two-way approach is confirmed by the significant correlations between measurement instruments found in this study. This shows that lack of convergence between tests can be reduced. It should be emphasized that this applies to the relation between the PTT and PAs but also to the mutual relationship between the PAs. Although differences in difficulty level between PAs exist, the significant correlations provide evidence that inconsistencies as reported in prior studies (e.g., Pine et al., 2006) can be reduced considerably and that the problem of occasion sampling variability can be tackled by administering more than one PA. The implication is that for reliable assessment of science skills, the implementation of multiple PAs should be considered. Also, instead of using one assessment format to assess students' performance of a scientific inquiry, a greater variety of test formats may provide a clearer picture of students' abilities (Gott & Duggan, 2002).

Previous studies showed that metacognitive skills have a positive influence on performing scientific inquiry (White & Frederiksen, 1998). In this study, no relations were found between the Jr. MAI, measuring general metacognitive ability, the PPT and all three

PAs. By contrast the SMT, constructed to obtain specific information about application of metacognitive abilities in performing science tasks, shows significant - although small - correlations with two PAs. This indicates that it is preferable to assess metacognition in performing scientific inquiry with items that are related to metacognitive activities in which students have a clear understanding of both science context and task. For young children, this may be especially essential.

The low or even lack of consistency between students' ability in performing scientific inquiry and their metacognitive self-assessment may be explained by the fact that students overestimate their own metacognitive skills. The scores on both the Jr. MAI and the SMT reveal that most students assess their own level of metacognition above the scale mean. It is therefore conceivable that many students in grades 5 and 6 are not yet able to utilize these metacognitive abilities while performing science tasks or, alternatively, simply do not master these skills even though they think they do. The latter seems most likely, given the low scores on the three items measuring specific metacognitive activities in the PAs (see Table 3.7). This is in line with Veenman, Van Hout-Wolters, and Afflerbach (2006, p. 9) who argued that scores on questionnaires "hardly correspond to actual behavioral measures during task performance". This is also consistent with the science curriculum in the Netherlands in which little to no attention is being paid to the acquisition of metacognitive skills in science lessons. The implication is that - when students do not yet show possession of the metacognitive skills with which to assess their own capabilities - it may be more appropriate to use other measurement methods such as thinking aloud methods.

Assessment in primary schools is dominated by recall of procedural knowledge and the practicalities of an inquiry but typically neglects the critical evaluation of results and own performance of the tasks (Osborne, 2014; Osborne & Dillon, 2008; Roth, 2014). By systematically including a more diverse set of items appealing to all cognitive abilities in both PPT and PAs a more valid representation of all aspects of scientific inquiry was obtained. In particular in the PAs, students obtained data by handling materials representing the practical aspects of the scientific inquiry. However, the larger part of the PAs included items in which students analyzed their own data and evaluated their own findings and performance, reflecting aspects of all three domains of activities (NRC, 2012).

The last research question concerned the extent to which the measurements may provide additional diagnostic information on subskill and step level. To that end, each activity performed in a scientific inquiry was classified by determining the primary skill underlying the activity. Although all subskills were applied in the assessments in an integrated manner (van Merriënboer, Clark, & de Croock, 2002), correlations between mean



scores of each subskill scale - consequently reflecting the main underlying skill applied in that particular cluster of activities - between the different measures indicate that a more precise identification of students' ability in performing scientific inquiry may be allowed. The acceptable scale reliabilities on subskill level for the PPT or aggregated across PAs indicate that scores can be used to obtain diagnostic information in addition to overall test scores. To illustrate, when scores on subskill level of the PPT (consisting primarily of multiple-choice items) are compared with the PAs, the scores on subskill level in the PAs are lower. This may indicate that it is more difficult for students to report their findings and formulate their own answers than to choose between alternative answers. This is also demonstrated by the small to medium correlations on subskill level between the different assessments (PPT and PA) indicating that the assessments on subskill level may differ. Also, concerning the PAs, it seems that on average students have more difficulty in completing items in which primarily thinking and metacognitive skills underlie the activities, compared to science-specific skills.

The systematic assembly of all aspects of a scientific inquiry can also create opportunities for evaluating students' scores at a more precise level. Within tests, differences between students' performance of the different activities of the empirical cycle are manifest. For instance, results on empirical step level show that students appeared to have more difficulty in designing an experiment than in formulating a research question. Moreover, scores for "measure and record" were low in both the PPT and PA, as were the scores for "analyze" and "conclusion" in the PA. A possible explanation for these findings may be that in both the PPT and PA, the step of measure and record included items in which students had to make a table and a graph. Being novices in performing a scientific inquiry, students most likely did not have the procedural knowledge to complete these items.

Nevertheless, it can be suggested that the operationalization of subskills and activities in the present study is rather indefinite. The subskill thinking, for example, still comprises a variety of mental processes such as problem-solving, making decisions, or creative thinking. And although items concerning, for example, designing an experiment were mainly categorized as science-specific based on the criterion that science-specific skills prevail in this activity, thinking and metacognitive skills are involved as well. This notion could also explain the small to medium correlations that exist between the different subskill scales within the assessments. This, together with the relatively low Cronbach  $\alpha$  coefficients on subskill and step level, implies that estimating students' development on scale level should be made with caution. A measurement with more items specifically aimed at only thinking or other skills may improve test validity and reliability but carries the risk of

becoming too detailed. Assessing all single aspects of the science skills separately may not have the same quality as assessing all aspects together in an integrated manner (Moseley et al., 2005), or in other words, the whole is more than the sum of its parts.

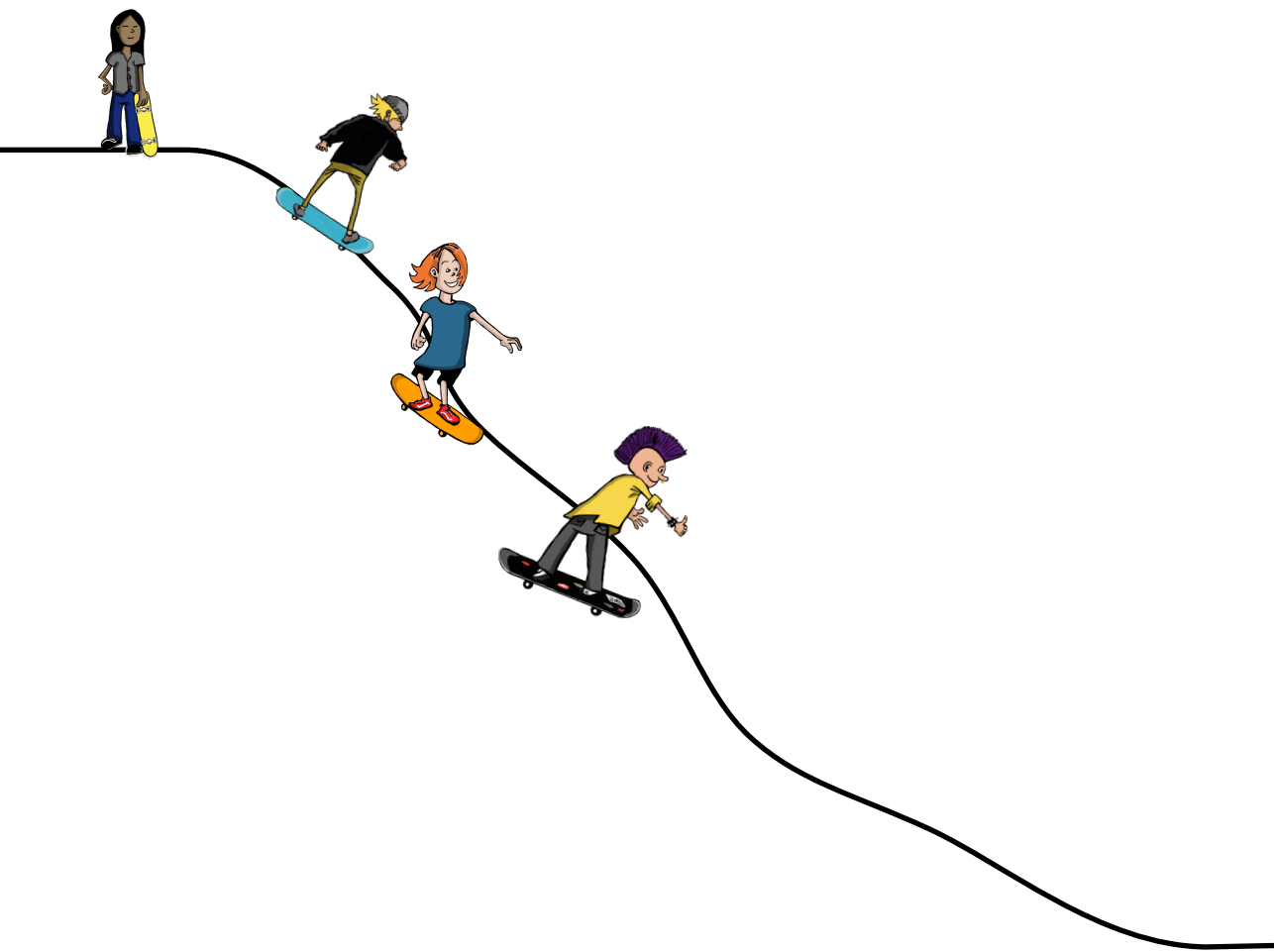
The constrained and scaffolded PAs seem suitable for students in primary education who are novices in performing scientific inquiry and do not yet master the required skills, although previous research shows that there is much variation between students in what they are capable of in terms of performing a scientific inquiry (Duschl, Schweingruber, & Shouse, 2007). The relatively low score means of the PAs suggest that, when exposed to actual teaching and practice of science skills, the PAs have potential to measure progress of students' skill ability. Furthermore, the added value of the measures is that by structuring items by subskill and step level, the opportunity to see how students perform on a cognitive and more detailed level is provided, as opposed to merely holistically assessing performance of a scientific inquiry. Such measures are not only suitable for assessing students' mastery level of science skills, but they may provide teachers with additional diagnostic information to adapt their instructions and foster the learning process of their students.

These measures may also stimulate teachers to implement assessments in their classrooms. Teachers are mostly concerned with science activities in the curriculum, often neglecting to assess what students have learned during these activities (Harlen, 1991). To some extent this may be attributed to lack of confidence with the use of more extensive tasks than with the easy-to-administer-and-grade tests containing primarily multiple-choice items (Harlen, 1991). Using a constrained PA may be less of an obstacle for teachers because of the more structured design and layout of the test. In addition, the particular format provides the opportunity to implement only parts of the PAs so that testing can be spread over more than one occasion. Moreover, the PAs can be embedded in science lessons as part of instruction material. It can be a start for familiarizing teachers with alternative assessment formats and may lead to greater confidence to implement more interesting and open inquiry tasks as students develop more skill expertise. Such tasks may eventually include aspects of scientific inquiry which are more complex and demand more of students' skill proficiency and amount of content knowledge. For instance, asking students to engage in argumentation about different experimental designs and connect their findings to bigger ideas in science (Osborne, 2014).

In primary education the acquisition of science skills is generally measured without systematically taking into account the complexity of underlying cognitive demands that students need to simultaneously apply in relation to different activities when conducting a scientific inquiry. Categorizing items on both subskill and step level provides more



opportunities for systematic test construction and improves concurrence of measurement instruments with different key content and formats such as a PPT and a PA. Furthermore, identifying and separating the various cognitive demands in assessments can help to evaluate and subsequently remedy the shortcomings of the particular skills and may also increase the emphasis in classrooms on the minds-on part of a scientific inquiry (Kind, 2013). As argued by Roth (2014), assessment of skills is important because it assures that skills are taught.



**effects** of explicit instruction  
on the acquisition  
of students' science inquiry skills  
in grades 5 and 6  
of primary education



## ABSTRACT

In most primary science classes, students are taught science inquiry skills by way of learning by doing. Research shows that explicit instruction may be more effective. The aim of this study is to investigate the effects of explicit instruction in an inquiry-based learning setting on the acquisition of inquiry skills for students in primary education. Participants included 705 Dutch 5th and 6th graders (aged 10-12 years). Students in an explicit instruction condition received an 8-week intervention of explicit instruction on inquiry skills. In the lessons of the implicit condition, all aspects of explicit instruction were absent. Students in the baseline condition followed their regular science curriculum. In a quasi-experimental pretest-posttest design, two paper-and-pencil tests and three performance assessments were used to examine the acquisition and transfer of inquiry skills. Additionally, questionnaires were used to measure metacognitive skills. Results of a multi-level analysis controlling for pre-tests, general cognitive ability, age, gender and grade-level indicated that explicit instruction facilitates the acquisition of science skills. Even though the paper-and-pencil test shows no effect, the scores on the performance assessment with a topic familiar to students show that students in both intervention conditions have significantly higher scores than students in the baseline condition. When skills are measured by means of a performance assessment with an unfamiliar topic, only students in the explicit condition outperform students of both the implicit and baseline condition. Therefore, this study provides a strong argument for including an explicit teaching method for developing inquiry skills in primary science education.

### Based on

Kruit, P. M., Oostdam, R. J., van den Berg, E., & Schuitema, J. A. (2018). Effects of explicit instruction on the acquisition of students' science inquiry skills in grades 5 and 6 of primary education. *International Journal of Science Education*, 40 (4), 421-441.

DOI: [10.1080/09500693.2018.1428777](https://doi.org/10.1080/09500693.2018.1428777)





## 4.1 Introduction

Scientific inquiry in primary classrooms generally involves designing, conducting and interpreting results of scientific investigations (National Research Council (NRC), 2012). These investigations are intended to teach skills that are considered important in science, such as formulating a research question and analyzing data. One of the intended outcomes is that students develop an understanding of why and how scientific investigations are done (Crawford, 2014). Skills for scientific inquiry are usually - if at all - taught by teaching methods primarily based on learning by doing (Duschl, 2008; Roth, 2014). In the Netherlands for instance, inquiry-based learning is advocated in primary education as the preferred method for acquiring content knowledge, science skills and epistemic knowledge (van Graft & Kemmers, 2007). In inquiry-based learning, students are encouraged to discover scientific knowledge and inquiry skills by performing authentic tasks (Kirschner, Sweller, & Clark, 2006). Proponents of inquiry-based learning argue that students learn best by actively constructing knowledge. Also, performing authentic inquiries is generally believed to be motivating for students (Gott & Duggan, 1995). As a result, many educators and curriculum developers have strongly recommended inquiry-based learning for science lessons (Kuhn, Black, Keselman, & Kaplan, 2000; Osborne & Dillon, 2008).

There is a growing body of research showing that explicit instruction is necessary to develop inquiry skills (Klahr & Nigam, 2004; Lazonder & Harmsen, 2016; Toth, Klahr, & Chen, 2000). Several studies have investigated the effects of explicit instruction on skill development in the laboratory setting, in particular on the strategy of controlling variables (CVS). Only a few studies have compared the effects of inquiry-based learning using explicit instruction with an inquiry-based approach absent of explicit instruction. The aim of this study is to investigate the effects of explicit instruction in an inquiry-based learning setting on the acquisition of inquiry skills for students in primary education.

### **Categorization of skills**

In order to understand how students learn and how to support learning, the current literature generally encourages the consideration of skill categories in scientific inquiry (Duschl, Schweingruber, & Shouse, 2007; Schraw, Crippen, & Hartley, 2006; Zohar & Dori, 2003).

In this study, the notion science-specific inquiry skills is used to denote a student's ability to design and execute scientific investigations. A distinguishing feature of these

inquiry skills is that they are directed to a correct application of rules, principles or conventions about the set-up and execution of an investigation (Millar & Lubben, 1996). Planning and performing an investigation requires explicit knowledge about how to conduct scientific experiments such as identifying and controlling variables, observing and measuring, using simple measurement devices, and recording, organizing and analyzing data (Gott & Murphy, 1987; NRC, 2012).

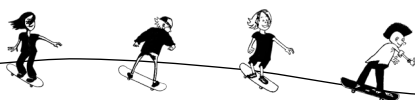
While engaging in scientific inquiry, students apply more general thinking skills to make sense of the data and connect observations to scientific theories (Osborne, 2015). Thinking skills refer to mental activities such as problem solving, decision-making, inductive versus deductive reasoning and evaluating solutions (Sternberg, 1986). Thinking skills are employed in scientific inquiry when making appropriate inferences from various sources of data and by drawing adequate samples for making inferences (Pintrich, 2002).

Knowledge and application of metacognitive strategies may regulate students' thinking and learning, thus supporting science inquiry (for overview, see Zimmerman, 2007). Metacognitive skills include planning, monitoring and evaluating task performance. Research shows that students do not apply metacognitive strategies spontaneously. Making students aware of such helpful strategies has shown to improve performance of inquiry activities (White & Frederiksen, 1998).

For science education it is relevant to consider the reciprocity of skill development and content knowledge. Content knowledge is most often referred to as a conceptual understanding of facts, concepts, theories and principles (Sternberg, 1986; OECD, 2017). A number of studies have shown that content knowledge is, to a certain extent, a prerequisite for skill development (Eberbach & Crowley, 2009; Kuhn, Schauble, & Garcia-Mila, 1992). In particular, when students generate hypotheses, make observations, evaluate evidence and draw conclusions, prior content knowledge can have a major effect on skill development (Duschl et al., 2007; Millar & Driver, 1987).

### **Explicit skill instruction**

Although there is evidence pointing to the acquisition of skills through learning by doing (Dean & Kuhn, 2007), a growing number of studies indicates that more effective learning occurs when inquiry-based learning is accompanied with explicit skill instruction (Duschl et al., 2007; Kirschner et al., 2006; Lazonder & Harmsen, 2016). Due to limited experience, most students in primary education lack sufficient mastery of strategies and knowledge to effectively conduct a scientific inquiry. Without explicit skills instruction, this leads to ineffective performance of scientific inquiry (Kirschner et al., 2006; Klahr & Nigam, 2004).



Engaging in a complex task of scientific inquiry without explicit skills instruction is particularly challenging for inexperienced students since their cognitive information processing capacity is still limited (Flavell, 1992). According to the Cognitive Load Theory (CLT), working memory is limited in its capacity to process new information that contains multiple elements. Elements have to be organized in more complex units and stored in long-term memory before the information can be used effectively (van Merriënboer & Sweller, 2005). Once this is achieved, information stored in long-term memory is accessible when needed, aiding the acquisition of inquiry skills (Kirschner et al., 2006).

Much of what is known about the effects of explicit instruction comes from studies on CVS (Lazonder & Egberink, 2014; Matlen & Klahr, 2013). For example, Chen and Klahr (1999) found in an intervention study with third and fourth graders that explicit instruction combined with probing questions (i.e., why they designed the investigations the way they did and what they had learned) was an effective way of learning how to apply CVS. This is in line with CLT because explicit forms of instruction put less of a burden on working memory when learning new information (Kirschner, et al., 2006). Dean and Kuhn (2007) showed that in particular explicit instruction (in which students were asked to compare and identify different features of catalogs) improved students' CVS more when combined with practice. The positive effects of explicit instruction may also apply to the acquisition of metacognitive skills. Explicit attention to awareness of the task and the metacognitive strategies may facilitate skill development (Pintrich, 2002; Tanner, 2012; Zohar & Dori, 2003).

Explicit skills instruction seems to be particularly important for fostering transfer of learning. More robust learning of skills has only been achieved when students are able to apply the skills in contexts other than the one in which the skills are learned. Although there is not a clear-cut definition of what different transfer distances entail (Chen & Klahr, 1999), near-transfer can generally be defined as the application of skills in tasks within a particular knowledge domain or with a common structure. Far-transfer is defined as the application of skills in tasks in different domains or tasks with an unfamiliar structure (Strand-Cary & Klahr, 2008).

While achieving transfer across knowledge domains (i.e., topics) is generally difficult (Kuhn et al., 1995; Lazonder & Egberink, 2014), some CVS studies have shown that explicit instruction can facilitate transfer of skills to other tasks with different topics (Klahr & Li, 2005; Kuhn et al., 1995). Likewise, research indicates that young students tend to fail in using the same strategies for performing tasks with different topics (cf. Chen & Klahr, 1999). Making students explicitly aware of the strategies and skills that they are applying to

a particular task leads to enhanced mastery which in turn may facilitate transfer (Adey & Shayer, 1993; Chen & Klahr, 1999; Georgiades, 2000).

### Four-component instructional design

When designing science lessons aimed at the development of science skills, the four-component instructional design (4C/ID) model can be applied. The model may be in particular suitable because the model focuses on the integration and performance of skills, as opposed to content knowledge (van Merriënboer, Jelsma, & Paas, 1992). Furthermore, the model recommends a combination of tasks in which skills are first practiced separately and then applied in more complex tasks in an integrated manner (van Merriënboer, Clark, & de Croock, 2002). Most of the difficulty in learning complex skills such as science skills is in applying them simultaneously. In existing design models, it is often assumed that complex skills acquired in simple tasks will be applied spontaneously to new and more complex tasks despite considerable evidence to the contrary (van Merriënboer et al., 2002, p. 40). According to the 4C/ID model, therefore, the following components are essential for developing skills: (1) whole learning tasks, (2) part-task practice, (3) supportive information, and (4) just-in-time information.

*Whole-tasks* represent authentic and meaningful scientific inquiries. Students receive explicit instruction and additional skills practice in *part-tasks*. The acquired skills can then be directly applied to more complex whole-tasks. This enables students to see the interrelationships between part-tasks and the task as a whole, stimulating the integration of skills (van Merriënboer et al., 2002). By segmenting the complex scientific inquiry activity into manageable smaller and structured part-tasks in which students can learn and practice skills, performance can be enhanced (Lazonder & Egberink, 2014; Lazonder & Kamp, 2012). Whole-tasks and part-tasks are preferably combined and sequenced from relatively simple to more complex (van Merriënboer & Sweller, 2005; Wu & Krajcik, 2006).

The structuring of the whole-tasks and part-tasks can be effectuated in science lessons by using the different steps of the empirical cycle as a design principle: (1) formulating a research question, (2) formulating hypotheses, (3) designing an experiment, (4) measuring and recording data, (5) analyzing and interpreting data, and (6) evaluating the outcomes in relation to the research question and hypotheses. Although it is generally acknowledged that scientific inquiry is not a linear process (NRC, 2012), the subsequent activities of the empirical cycle provide a structure that is recognizable for students. It also gives an understanding of how the inquiry process may be organized, which is particularly



on the acquisition of student's science inquiry skills in grades 5 and 6 of primary education

important for students in primary education who have little experience with scientific inquiry (Donovan, Bransford, & Pellegrino, 1999; White & Frederiksen, 1998).

Another aspect of the 4C/ID model is *supportive information*, which comprises the information students do not possess needed for performing a particular scientific inquiry. Finally, *just-in-time information* refers to essential clues, knowledge or feedback students have access to the moment they need it during task performance. Just-in-time information can consist of prompts which are gradually withdrawn as students gain proficiency (McNeill et al., 2006). Prompts can take the form of generic 'probing questions' or hints to encourage reflection which helps students to set goals and monitor their understanding (Sahin & Kulm, 2008). Eventually, prompts can gradually be withdrawn until students can apply the acquired skills independently (White & Frederiksen, 2000).

An example of implementing prompts for explicit instruction of metacognitive skills is the application of the TASC framework. TASC stands for "Thinking Actively in a Social Context" and aims to give young students structure to support their thinking (Wallace, Bernardelli, Molyneux, & Farrell, 2012). Students can be instructed on how to move systematically through the stages of the TASC framework while performing a task. In each stage, several questions can be raised to stimulate students to monitor and evaluate their performance (Figure 4.1). For instance, the students are asked to think about what they already know about the topic of an experiment, how much information they already have, and what information they need (Wallace et al., 2012). These questions are introduced and eventually withdrawn gradually until students are familiar with the questions and apply the metacognitive skills in each following experiment by themselves (White & Frederiksen, 2000).



**Figure 4.1**  
**TASC Framework**

### The present study

The present study adds to the current discussion by investigating the effects of explicit instruction on the acquisition of inquiry skills in classroom settings in grades 5 and 6. Furthermore, it examines to which extent the acquired skills are utilized in tasks with

content different from the tasks used in the science lessons. Contrary to most studies (Shavelson et al., 1991), skills were not only evaluated by a paper-and-pencil test, but also by more authentic performance assessments. Additionally, questionnaires were used for evaluating improvement in metacognitive skills.

The following research questions concerning explicit skill instruction in grades 5 and 6 were addressed: (1) What are the effects on students' skills in scientific inquiry?, and (2) What are the effects on transfer of students' skills across science tasks with unfamiliar content?

In line with current knowledge on enhancing skill development, it was hypothesized that receiving explicit skill instruction would positively affect students' science skills and that the merits of explicit instruction would also extend to transfer of students' skills.



## 4.2 Method

### Participants

This study was conducted at 12 schools for primary education in the Netherlands. It involved schools that were part of the school network with which the teacher training education of the Amsterdam University of Applied Sciences cooperates. As a result, the schools were located in the urbanized part of the Netherlands. Schools were willing to participate on the basis of several pragmatic factors including permission of school authorities, interest of teachers, willingness to do something with science and available time.

To ensure that the reading and writing abilities of students would not be a limiting factor in relation to the acquisition of science skills, only students in upper grades were included. In total, 705 students participated in the study (51.3 % boys and 48.7 % girls) with a mean age of 11,5 ( $SD = .69$ ) from 31 grade 5 and 6 classes (53.3 % in grade 5 and 46.7 % in grade 6).

### Research design

The research constituted a quasi-experimental study with pretest-posttest design, implemented in grades 5 and 6 of primary schools, designed to investigate the effects of explicit instruction on students' acquisition of inquiry skills (explicit condition). A control condition was included with lessons in which skills were taught in an inquiry-based approach without explicit instruction on inquiry skills so that information about the added value of explicit instruction could be obtained. To contrast both controlled conditions with regular science lessons at schools, a baseline condition was added. Randomization was carried out within schools at class level.

A total of 705 students participated in the pre-test sessions. Pre-testing included three different measures: a paper-and-pencil-test (PPT), a performance assessment (PA) and a metacognitive self-report test (Jr. MAI). After an 8-10 week period students of all three conditions were tested again with a PPT, two PAs (*PA-related-content* with a topic discussed in lessons of both interventions and *PA-transfer* with an unfamiliar topic designed to measure transfer of skills), Jr. MAI and an extra metacognitive self-report test (SMT). Additional measures for the explicit and implicit conditions included an implementation checklist on class level and a questionnaire for evaluating how enjoyable the lessons were perceived by the students.

PAs were administered in small groups of students outside of the regular classroom, which required additional time and effort for the schools and students. Therefore, to reduce the burden, a subsample ( $n = 467$ ) was randomly selected to partake in the post-test PAs. The subsample was created by random selection of students in each class. To enable comparison between tests, only students who had completed all tests were included for final analysis. Of the subsample, 62 students were excluded due to having been absent from one of the test sessions. Finally, one class which consisted of only two students was dropped from the analysis to prevent estimation bias in multilevel analysis (Maas & Hox, 2005). The final sample consisted of 403 students (Figure 4.2).

Recruitment and allocation to conditions	$N = 705$		
	<b>Explicit condition</b>	<b>Implicit condition</b>	<b>Baseline condition</b>
	$n = 257$	$n = 235$	$n = 213$
Pre-test	PPT, PA, Jr. MAI		
Intervention	Explicit instruction	Implicit instruction	-
Intervention-related measures	Lesson enjoyment questionnaire Implementation		
Post-test	$N = 467$		
	PPT, PA-related-content, PA-transfer, Jr. MAI, SMT		
	Not included in final analysis: $n = 64$		
	$n = 144$	$n = 138$	$n = 121$

**Figure 4.2**  
*overview of the study design*

### Intervention

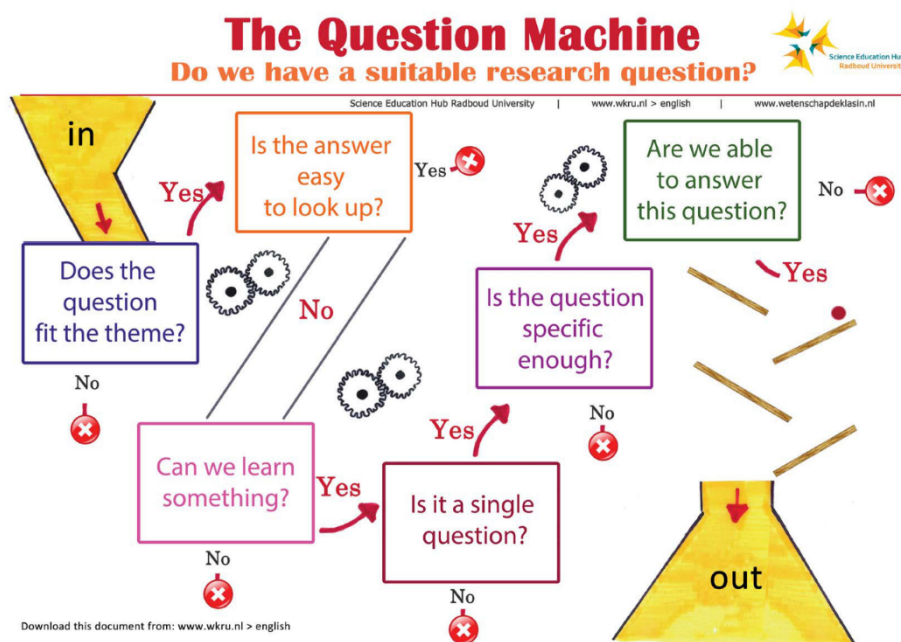
The lessons for the intervention were developed by the first author and a primary school teacher. The aim was to enhance development of skills associated with scientific inquiry. Each intervention consisted of eight lessons of 90 minutes each. In general, one lesson was given per week. During this time, students in the baseline group followed their regular curriculum and did not receive any formal instruction on scientific inquiry.





### Explicit condition

The lessons for the explicit condition were designed based on the 4C/ID model of Van Merriënboer et al. (1992). The whole-tasks and part-tasks were structured according to the different steps of the empirical cycle. The topic was heat and temperature. The content knowledge was minimized in the sense that it was addressed at such a low level such that it could be assumed that it would pose no obstacle in skill application. For instance, students at grade levels 5 and 6 are aware of the fact that hot water cools down and that temperature can be measured by using a thermometer.



**Figure 4.3**

*flow chart with criteria for formulating a research question*

Explicit instruction concerned clarifying the rationale of inquiry skills by the teacher followed by examples and classroom discussions about how to apply the skills. In part-tasks, the newly learned skills were then practiced with the support of written prompts. For example, in learning how to formulate a research question, the teacher gave explicit instruction about the criteria for formulating research questions with the help of a flow chart (Figure 4.3). In subsequent part tasks where students were asked, for instance, to distinguish between properly and poorly formulated research questions, students were

reminded of the flow chart. Next, students performed a whole-task: an authentic, structured inquiry in which students had to apply all skills in an integrated manner. In these whole-tasks, prompts were explicitly incorporated as well. Development of metacognitive skills was supported by the use of probing questions from the TASC framework prior to and during each whole-task (Wallace et al., 2012).

During the course of the intervention, the whole-task inquiries gradually increased in difficulty and complexity while at the same time, the prompts were withdrawn. In the final lesson students performed a scientific inquiry independently.

### **Implicit condition**

The lessons of the implicit condition were structured based on the 4C/ID model as well. Students in the implicit condition also performed inquiry tasks that were structured according to the different steps of the empirical cycle. All aspects of explicit instruction were absent which entailed that the teacher refrains from explaining the rationale behind the skills and that in part-tasks and whole-tasks, skills were practiced without explicit probing questions or prompts. Rather than giving explicit attention to separate skills first and then part-task practice on skill level, all skills were applied and practiced simultaneously. To control for time on task, the implicit intervention contained part-tasks about content and additional topics were included (see Appendix E for both explicit and implicit example tasks). Two lessons concerned growth and development of plants, two lessons on heart and lungs followed by the main topic of heat and temperature (four lessons). Ultimately, the implicit intervention comprised similar numbers of scientific investigations and assignments (Table 4.1).

Both interventions were piloted in several grade 5 and 6 classrooms which did not participate in the main study. Adjustments were made where necessary, which in general concerned length of assignments or difficulty level of scientific inquiry tasks.

### **Baseline condition**

In Dutch primary schools, science lessons are primarily textbook-based. Developing inquiry skills has low priority in science primary education, indicated by the lack of implementation of instruments to measure progress of skills (Inspectorate of Education, 2015). Inquiry tasks are included at most once a month or less and only by 50% of the teachers (Kneepkens, Van Der Schoot, & Hemker, 2011). Students in the baseline condition did not receive formal and structured instruction on inquiry skills during the intervention period.



**Table 4.1**  
*similarities and differences between the explicit and implicit condition*

aspect	explicit condition	implicit condition
similarities		
duration	Eight lessons of 90 minutes	Eight lessons of 90 minutes
whole-task	Authentic investigations	Authentic investigations
differences		
structure of investigations	Investigations <u>explicitly</u> structured for the students according to steps of empirical cycle	Investigations <u>implicitly</u> structured for the students according to steps of empirical cycle
part-task	Part-tasks for skill training	Part-tasks for acquisition of content knowledge
just-in-time information	Prompts	No prompts
metacognition	Explicit attention to planning, monitoring and evaluation	No attention to planning, monitoring and evaluation
instruction	Direct instruction on skills	No direct instruction on skills
content of lessons	Heat and temperature	Heat and temperature, growth and development of plants, heart and lungs

Applying the hypothesis to the experimental design, it was predicted that students in the explicit condition would improve their ability to perform a scientific inquiry more than students in the baseline condition. Furthermore, it was expected that students in the explicit condition would also outperform students in the implicit condition since the benefits of explicit instruction, including prompts, task-structuring and direct instruction have been well-established (Lazonder & Egberink, 2014; van Merriënboer & Sweller, 2005; Zohar & Dori, 2003). Furthermore, it was predicted that the explicit instruction combined with part-task practice aimed at skill acquisition would be specifically beneficial for skill performance in the transfer task (Chen & Klahr, 1999). However, since practicing and applying skills in whole scientific inquiry tasks alone can also enhance skill development to some extent (Dean & Kuhn, 2007), we expected that students in the implicit conditions would also improve science skills more in comparison to students in the baseline group.

## Procedure

The lessons of both interventions were taught by research assistants who had been recruited and trained specifically for this purpose. All assistants had either graduated or were in the final year of an elementary teacher education program. The students' regular teacher was asked to assist in each lesson. The presence of a familiar teacher would help maintain a good working atmosphere while teaching. All lessons were taught in the students' regular classroom and with their regular classmates.

The research assistants were trained in a 4-hour training session to teach either one of the interventions. Training included instruction, discussion and practice of parts of lessons. In addition, assistants were trained in how and when to provide feedback during tasks. The assistants were provided with a practical guide containing a description of the rationale behind the intervention, detailed lesson plans and information on the skills and content to be covered in the lessons. In addition, to ensure that all assistants would stay on the same track (and no parts would be skipped), PowerPoint presentations were developed for each lesson. In that way, it was assured that all assistants would implement the lessons in a similar way.

To check the faithfulness of the implementation, the regular teacher was asked to monitor the degree of implementation of the activities of each lesson. In addition, the research assistants were monitored by two of the authors by observing a randomly chosen lesson. Throughout the intervention, research assistants and the main author kept in close contact by discussing lessons regularly. Furthermore, each research assistant was asked to film lesson 7 of which random parts were watched by the author for a fidelity check. Additionally, information on student level was collected documenting lesson attendance and to what degree the students found the lessons enjoyable, because both may influence students' participation and scores.

Teachers in the baseline group did not receive any of the materials used in the interventions. However, to be assured of cooperation, they could choose to complete one of the two interventions with materials and trained assistants after the experiment.

## Measurement instruments

### Paper-and-pencil test

Students' inquiry skills were measured by means of a paper-and-pencil test (PPT). The test comprised a total of 46 items (36 multiple choice and 10 open-ended), which were based on items selected from large-scale assessments commonly used in the Netherlands (Cito.com) and other sources (e.g., SOLpass.org). Content varied from item to item and was considered



on the acquisition of student's science inquiry skills in grades 5 and 6 of primary education

to be familiar for grade 5/6 students. The 10 open-ended questions were scored by trained raters.

For pretest-posttest purposes, the items were divided into two test booklets to give two optimal split half tests. A total score for each test was calculated with a maximum possible score of 30 points. The Cronbach's alpha coefficients of the pre-test and post-test were .63 and .70 respectively ( $n = 403$ ).

#### Performance assessments

Students were additionally assessed by three PAs. All three PAs concerned comparative investigations: students are asked to examine the relationship between two variables (Shavelson, Solano-Flores, & Ruiz-Primo, 1998). Each PA was constructed according to the same template, following the different activities of the empirical cycle and allowing for comparison of students' scores between PAs. PAs differed only in topic of investigation. In the *PA-pre-test Skateboard*, students roll a marble down a ruler to examine the relation between the distance of the marble on the ruler and the distance the marble covers at the end of the ruler while pushing forward a paper wedge (Ahlbrand, Green, Grogg, Gould, & Winnett, 1993). The PAs *Hot Chocolate* and *Bungee Jump*, based on tasks in TIMSS (Martin et al., 1997), were deployed for post-testing. *Hot Chocolate (PA-related-content)* concerns the relationship between an amount of hot water and its rate of cooling, which corresponds to the topic of heat and temperature addressed in both intervention groups. In *Bungee Jump (PA-transfer)* students investigate the changing length of a rubber band as additional weights are added, a topic unfamiliar to both groups. This last test served to assess the transfer of skills to a new task.

Each PA contained 14 quantifiable items with a maximum score of 34 points (see Appendix F for *PA-pre-test Skateboard*). Scoring of items was based on students' answers written down in worksheets. The Cronbach's alpha coefficients of *PA-pre-test*, *PA-related-content* and *PA-transfer* were .67, .70 and .67 respectively ( $n = 403$ ).

#### Metacognitive self-report tests

Metacognitive skills were measured by means of two different self-report tests. For pre- and post-testing purposes, the Junior Metacognitive Awareness Inventory (Jr. MAI), a self-report inventory for grades 3-5 developed by Sperling, Howard, Miller and Murphy (2002) was administered. Jr. MAI consisted of 12 items with a three-choice response (never, sometimes, or always). The mean score was calculated to obtain a measure of general metacognitive ability. The pre-test and post-test Cronbach's alpha coefficients were .54 and .64 respectively.

The second metacognitive self-report test - Science Meta Test (SMT) - measures metacognitive self-regulatory skills including orientation/planning, monitoring and evaluation (Schraw & Moshman, 1995). In contrast to the more general Jr. MAI, items were constructed to obtain information about the extent to which metacognitive skills are applied specifically in the PAs in post-testing. A mean score was calculated of the total of 13 items with a three-point scale (not, a little, a lot) and an alpha of .77 ( $n = 403$ ).

#### General cognitive ability

To be able to control for general cognitive ability, students' scores were obtained for Reading comprehension and Arithmetic/mathematics from a semi-annual assessment of The National Institute for Educational Testing and Assessment. For Reading comprehension and Arithmetic/mathematics, reliability scores indicated by MAcc (Accuracy of Measurement) are  $>.87$  and  $>.95$  respectively for grades 5 and 6 (Janssen, Verhelst, Engelen, & Scheltens, 2010; Weekers, Groenen, Kleintjes, & Feenstra, 2011). Ability is expressed by different levels which indicate the actual performance level of a student compared to a norm group (A=upper 25% of all children, B=25% above mean, C=25% below mean, D=next 15% below C, E=lowest 10%). The scores, provided by the participating schools, were transformed into a five-point scale (A=5 to E=1). A student's general cognitive ability score was constructed by means of summing up the scores of both tests.

### **Intervention-related measures**

#### Integrity of implementation

Degree of implementation was measured by the percentage of instruction and activities of each lesson actually carried out. A class level variable representing the degree of implementation was calculated by averaging the percentages of the number of lessons of each class.

#### Lesson enjoyment

Students were asked to fill out a short questionnaire of 7 items with a five-point Likert scale at the end of the final lesson of the intervention. The original questionnaire was developed for measuring enjoyment of math lessons by Martinot, Kuhlemeier, and Feenstra (1988). The items were adapted for primary science lessons and an extra item was added. A final score was calculated by summing the scores (maximum of 28) of each item ( $\alpha = .84$ ).



### **Administration procedure**

The PPT-pre-test, PA-pre-test and Jr. MAI-pre-test were administered in this specific order just before the start of the intervention. Post-testing comprised the PPT-post-test, PA-related-content, PA-transfer and the two metacognitive self-report tests. To control for sequencing effects, administration of PA-related-content and PA-transfer was randomly alternated. Post-Jr. MAI and SMT were administered directly after PA-transfer, taking just a few minutes to complete.

All tests were administered by trained test leaders who followed detailed protocols for test administration. The PAs were administered individually in groups of 4-8 students. The PPT and PA each took 45 minutes to complete.

### **Scoring**

Trained raters scored the open-ended questions for the PPTs and PAs. Interrater reliability was calculated by determining intra-class correlation after a training session on a random sample of 11% of the tests. Additionally, another average of 19% of the scores per rating session were scored by two raters so that additional interrater reliability could be estimated during the process of individual rating. First round ICC ranged from .80 to .94 (ICC, two-way random, absolute agreement), and second round from .66 to .93. Finally, for each rater, stability of scoring was estimated which ranged from .81 to 1.00.

### **Analysis**

An a priori power analysis indicated that a sample of 68 students would be sufficient to test a main intervention effect of medium size with a statistical power of  $\beta = .80$  at the conventional alpha level of .05 with multiple regression analysis. The sample of more than 400 students allows a test of small-to-medium effect sizes, also taking into account intracorrelations (ICC values between .10 - .30).

The dataset included one independent variable (condition: explicit instruction, implicit instruction, baseline) and five dependent variables (Post-PPT, PA-related-content, PA-transfer, Post-Jr. MAI and SMT). Because of the nested structure of the data, multilevel models were used to investigate the effects of the conditions on the five dependent variables. MLwiN for multilevel analysis (Rasbash, Steele, Browne, & Goldstein, 2009) was used to fit five different models (one for each dependent variable) with two levels (students within classrooms). Adding a third level for school did not significantly improve the fit of the models.

The student variables (age, gender and general cognitive ability), grade level and pre-test scores were included as control variables since they might influence students' scores. Variables were examined for accuracy of data entry, distributions and missing values. All underlying assumptions (i.e., normality) were met.

As explained above, 64 students were not present at one or more test sessions. These students were excluded from further analysis (Figure 4.1). There were no missing values on individual items in the PPTs and PAs. There was a maximum of 6.7 % missing values on items of all three metacognitive self-report tests. Little's MCAR test including all variables was not significant, indicating that no identifiable pattern existed in the missing data ( $\chi^2 (5552) = 5470.73, p = .78$ ). Of the students who were present for all test sessions, the expectation-maximization (EM) imputation method was performed for the missing items of each metacognitive self-report test separately.

Ultimately, the Jr. MAI test was not included in the analysis because of insufficient reliability of the pre-test ( $\alpha = .54$ ) and a serious lack of variance at the post-test. For the benefit of interpretation of the intercept, all continuous control variables were centered around the grand mean.





## 4.3 Results

### Descriptive statistics

Table 4.2 presents the effects of randomization on the composition of the three conditions. Conditions were comparable with regards to gender ( $\chi^2(2) = 2,3, n = 403, p = .319$ ), but not to grade level, with more students in grade 6 in the implicit condition compared to the other conditions ( $\chi^2(2) = 8,10, n = 403, p = .017$ ). ANOVA analyses indicated that students between conditions did not differ significantly on general cognitive ability ( $F(2, 400) = .77, p = .465$ ). There was a significant difference in age ( $F(2, 400) = 5.13, p = .006$ ), with students in the baseline condition being somewhat younger than students in the implicit condition (Mean Difference =  $-.26$ , CI =  $-.46$  to  $-.07$ ). Of the pre-tests, conditions did not differ in scores for the PPT-pre-test ( $F(2, 400) = 1.20, p = .302$ ). However, analysis showed significant differences between scores on the PA-pre-test ( $F(2, 400) = 3.54, p = .030$ ) with a lower score for the explicit condition.

**Table 4.2**  
*comparison of conditions in terms of the control variables*

condition	n	gender %		grade %	
		boy	girl	5	6
explicit	144	46.5	53.5	54.9	45.1
implicit	138	54.3	45.7	42.0	58.0
baseline	121	46.3	53.7	58.7	41.3

condition	general ability	age	PPT pre-test	PA pre-test
	mean (SD)	mean (SD)	mean (SD)	mean (SD)
explicit	7.15 (2.35)	11.44 (.65)	15.04 (4.21)	9.69 (4.29)
implicit	6.80 (2.46)	11.61 (.72)	15.52 (4.51)	11.24 (5.07)
baseline	6.92 (2.24)	11.34 (.62)	15.88 (4.51)	10.14 (5.64)

*Note: maximum possible score of PPT-pre-test is 30 and of PA-pre-test is 34 points*

### Descriptive statistics of intervention-related measures

Of the total of 168 lessons in the explicit and implicit condition taught in 21 different classrooms, an implementation score was missing from 4 lessons. For the classes with missing scores, an average score was calculated on the basis of the lessons scored.

Multilevel regression analysis showed that the degree of implementation for the implicit condition ( $n = 144$ ) was not significantly different to that of the explicit condition ( $n = 138$ ), ( $B = 2.38$ ,  $SE = .176$ ,  $p = .174$ ).

An independent-samples  $t$ -test showed no significant difference in enjoyment ( $t(237) = 1.56$ ,  $p = .121$ , equal variances not assumed) between students of the implicit condition ( $M = 18.11$ ,  $SD = 5.40$ ) and those of the explicit condition ( $M = 16.88$ ,  $SD = 7.20$ ).

Finally, an independent-samples  $t$ -test indicated that students' number of attended lessons did not differ significantly between the explicit condition ( $M = 7.60$ ,  $SD = .73$ ) and the implicit condition ( $M = 7.70$ ,  $SD = .64$ ),  $t(280) = -1.12$ ,  $p = .264$ .

### Descriptive statistics of post-tests and correlations

Table 4.3 presents the means and standard deviations for all post-tests. Because scales of the scores are different for each test, the means are not comparable one-on-one.

Table 4.4 shows the correlations (Pearson's  $r$ ) between tests. No significant correlations were found between the SMT and other tests, other than PA-transfer. Results show that general cognitive ability is considerably correlated with pre-tests as well as the PPT-post-test, whereas correlations with post-PAs are smaller.

**Table 4.3**  
*means and SD for post-tests*

	max score	explicit ( $n = 144$ )		implicit ( $n = 138$ )		baseline ( $n = 121$ )	
		M	SD	M	SD	M	SD
PPT	30	16.56	4.59	16.52	4.94	15.40	5.02
PA-transfer	34	13.72	4.69	12.53	5.59	11.30	5.07
PA-related-content	34	13.67	4.74	13.49	5.50	10.39	4.88
SMT	3	2.12	.41	2.11	.35	2.16	.31

*Note: max score = maximum score possible of test; Mean and SD of SMT are indicated by average item scores*

### Effects of interventions on skills in scientific inquiry

Table 4.5 presents the results of the multilevel analysis on the effects of condition on skills in scientific inquiry, controlling for pre-tests, general cognitive ability, age, gender and grade level. Results show that the effects of age and grade level were not significant. The two pre-tests and general cognitive ability positively contributed to the scores of all three post-tests. There was also an effect of gender: girls scored significantly higher on the tests than did boys. Adding the condition variable did not significantly increase model fit for the



**Table 4.4**  
**correlations between all tests ( $n = 403$ )**

	1	2	3	4	5	6
1 PPT-pre-test						
2 PPT-post-test	.60*					
3 PA-pre-test	.54*	.52*				
4 PA-transfer	.39*	.47*	.52*			
5 PA-related-content	.36*	.45*	.43*	.63*		
6 SMT	.02	-.03	.04	.15*	.01	
7 General cognitive ability	.58*	.57*	.49*	.35*	.34*	-.04

\* correlations are significant at  $p < .01$  (2-tailed)

PPT ( $\Delta IGLS = 3.64$ ,  $df = 2$ ,  $p = .162$ ). Effect sizes in terms of Cohen's  $d$  (Cohen, 1992) were small for both the explicit condition ( $d = 0.27$ ) and implicit condition ( $d = 0.20$ ). These results indicate that there was no significant effect due to the interventions on the ability of students to apply skills in the PPT. In contrast, condition did have a positive significant effect on scores of the dependent variable PA-related-content ( $\Delta IGLS = 15.84$ ,  $df = 2$ ,  $p < .001$ ). Students of both intervention conditions did significantly better than students in the baseline condition with medium effect sizes  $d = 0.66$  for the explicit condition and  $d = 0.58$  for the implicit condition. The interventions also contributed to a significant better model fit for PA-transfer ( $\Delta IGLS = 8.09$ ,  $df = 2$ ,  $p = .018$ ). However, in contrast to PA-related-content, only the estimate for the explicit condition was significantly higher than the baseline condition ( $B = 2.48$ ,  $SE = .82$ ,  $p = .003$ ) with medium effect size  $d = 0.48$ . The effect size for the implicit condition was small ( $d = 0.18$ ). In other words, only explicit instruction had a positive effect on the ability to perform an investigation with a new and unfamiliar topic.

To further explore the difference between the two intervention conditions, multilevel analysis was performed on a subsample of students ( $n = 282$ ) who had received either explicit or implicit instruction. In addition to the pre-tests, general cognitive ability, age, gender and grade, the treatment fidelity variable 'implementation' was added as class-level control variable. Only on the performance assessment PA-transfer, the model fit improved significantly by adding condition ( $\Delta IGLS = 4.98$ ,  $df = 1$ ,  $p = .026$ ). Specifically, the students who received explicit instruction performed significantly better ( $B = 2.00$ ,  $SE = .86$ ,  $p = .016$ ) than students in the implicit condition. The magnitude of the effect could be considered moderate with  $d = 0.40$ .

For the metacognitive skills evaluated by the students with the SMT, no additional variance was explained by condition, indicating that condition had no effect on scores.

**Table 4.5**  
**results of the multilevel analyses for each dependent variable ( $n = 403$ )**

	PPT-post-test			PA-content-related post-test			PA-transfer post-test			SMT		
	coeff	SE	p	coeff	SE	p	coeff	SE	p	coeff	SE	p
intercept	14.83	0.61	<.001	8.90	0.73	<.001	9.87	0.73	<.001	2.18	0.06	<.001
PPT-pre-test	0.33	0.05	<.001	0.14	0.07	.028	0.13	0.06	.042			
PA-pre-test	0.19	0.05	<.001	0.21	0.06	<.001	0.35	0.05	<.001			
general ability	0.61	0.10	<.001	0.45	0.12	<.001	0.35	0.12	.003	0.00	0.01	n.s.
age	-0.08	0.39	n.s. <sup>4</sup>	-0.08	0.48	n.s.	0.55	0.45	n.s.	0.02	0.04	n.s.
gender <sup>1</sup>	0.79	0.35	.021	2.65	0.42	<.001	2.73	0.39	<.001	-0.02	0.04	n.s.
grade <sup>2</sup>	0.35	0.61	n.s.	0.15	0.74	n.s.	0.07	0.71	n.s.	-0.03	0.06	n.s.
condition												
explicit condition <sup>3</sup>	1.31	0.68	.055	3.48	0.81	<.001	2.48	0.82	.003	-0.04	0.07	n.s.
implicit condition <sup>3</sup>	0.98	0.70	n.s.	3.05	0.83	<.001	0.91	0.84	n.s.	-0.05	0.07	n.s.
explained variance %												
group level		61.07			65.86			60.50			.00	
student level		45.39			26.94			34.22			.00	
ICC		.12			.11			.14			.09	

Note: <sup>1</sup> reference category: boys; <sup>2</sup> reference category: grade 5; <sup>3</sup> reference category: baseline condition; <sup>4</sup> not significant



## 4.4 Discussion

Results of this study confirm that both experimental interventions facilitate the acquisition of skills for performing scientific inquiry. The scores on the PAs show that students in both intervention conditions have significantly higher scores than students in the baseline condition. In particular, when skills are measured by means of a PA with a topic familiar to the content of the lessons, substantial effects are found. This finding is consistent with former research on the influence of content knowledge on developing skills (Duschl et al., 2007).

Furthermore, comparison of the two experimental conditions reveals that students of the implicit condition were almost just as able to perform the scientific inquiry on a familiar topic as students who received explicit instruction. Although most studies (on CVS) show more effective learning by explicit instruction, this finding suggests that in a carefully structured setting the opportunity to practice skills alone can already improve skill application which concurs with former findings (Dean & Kuhn, 2007).

On a PA with an unfamiliar topic, scores are particularly interesting. Indicated by a medium effect size, students in the explicit condition clearly outperform students in the implicit condition. In both conditions, students had been practicing the same number and variety of inquiries but only students subjected to explicit instruction were able to apply inquiry skills in a PA with unfamiliar topic. This indicates that explicit instruction facilitates (near) transfer of skills, which seems concordant with findings in CVS studies (e.g., Chen & Klahr, 1999; Klahr & Li, 2005). In the present study, systematic and explicit attention (i.e., by prompts) to skills in new tasks may have promoted more robust acquisition of these skills. Increased awareness of strategies applied in the tasks by means of probing questions may have further strengthened skills acquisition. The decontextualization of skills has possibly contributed to students' ability to apply the skills they acquired by practicing tasks with different science content, albeit in the same domain (near-transfer). This implies that students were not only able to use these skills, but actually understood how to apply them, which has been shown to be difficult to accomplish in a classroom setting (cf. Klahr & Li, 2005).

The improvement of skills measured by the PPT was much smaller - though almost significant - for students in the explicit condition and as such did not match the outcomes of performance measured by the PAs. This discrepancy may be due to the different test format. Skills measured by the PPT were elicited in a more passive manner in contrast to applying skills actively in a PA which is considered a more authentic way of assessing skills

(Shavelson et al., 1998), thus measuring actual skill proficiency. For instance, formulating a research question for a “real” inquiry is not the same as identifying a research question among different multiple-choice options. Accordingly, a PPT may not be the most appropriate way to assess skill performance. The structure of the items in the PPT were less similar to the tasks in the interventions lessons and as a result students could depend less on skills learned in the lessons. Instead, students had to rely more on general abilities in the PPT than in the PAs, which is supported by the small/medium correlation found between post-test PAs and general cognitive ability ( $r = .35$  and  $.34$ ) and the medium/large correlation between the PPT and general cognitive ability ( $r = .57$ ).

Results show no significant difference in scores between students in grade 5 and 6, even when age was removed from the model. Upon first glance, this is a surprising outcome as students are likely to have improved their skills just by growing older and acquiring more general skills by the time they are in grade 6 (Duschl et al., 2007). This may indicate that students participating in this study had very little prior experience with scientific inquiry, thus were novices regardless of what grade they were in. The implication may be that both the design of the instructions as well as the implemented assessment formats are suitable for students of both grade levels, provided that all students share the same (lack of) experience with scientific inquiry.

Despite the improvement of skill proficiency, the SMT failed to elicit development of metacognitive skills. However, it is very unlikely that students - as the high scores above the scale mean suggest - already possess the ability to apply metacognitive skills to scientific inquiry and therefore could not improve their metacognitive skills at all, regardless of any instruction. A more plausible explanation could be that students overestimate their metacognitive skills. This is in line with Veenman, Van Hout-Wolters and Afflerbach (2006) who stated that scores on questionnaires “hardly correspond to actual behavioral measures during task performance” (p. 9). It is therefore conceivable that many students in grades 5 and 6 do not yet have a mastery of these skills even though they thought they did. Nevertheless, it may be that the metacognitive skills did improve and - although not directly measured by the SMT - are indirectly reflected in higher scores on the PAs (Georghiades, 2000).

### Limitations and suggestions for future research

An important limitation of this study is that teaching assistants were using the lesson materials for the first time. In a repeat teaching, assistants may be more efficient and effective which could result in greater gains compared to the baseline condition.



on the acquisition of student's science inquiry skills in grades 5 and 6 of primary education

A second limitation in the design of this study is that only two post-PAs were included. Assessing skill proficiency with more PAs would be preferable in order to reduce occasion sampling variability, i.e., students performing the same task differently on different occasions (Ruiz-Primo, Baxter, & Shavelson, 1993). However, the PAs in this study were made quite elaborate in a bid to resemble authentic research. Deploying more of such extensive assessments in real classroom settings would be laborious for students and require too much testing time.

Furthermore, in this study the PAs are highly structured and not, as such, representative of scientific inquiry, which is not generally a linear process. However, for students who are novices, open investigations may be too challenging. In further research, students could be assessed as their proficiency increases, using more open and interesting investigations. Along the same lines, although the PPT was easy to administer and less difficult to score, it may not have been the best choice for measuring progress of skills of the novice learners in this study. The PAs provided a more elaborate and detailed picture of the acquired skills and may have been as such more sensitive to change.

Finally, the post-tests were administered directly following the intervention. This implies that only the short-term effects on inquiry skills of the explicit and implicit teaching method were measured. A retention test was not included in the design because the grade 6 students were no longer available for another round of post-testing. Future research might examine retention and/or transfer by using tasks with a different or more open structure.

### **Implications for educational practice**

The current study has several practical and scientific implications. For students in primary school who have little experience with scientific inquiry, systematic, explicit instruction should be considered and incorporated as a starting course for developing skills. As students gain more proficiency in both skills and content knowledge, more open and interesting inquiry activities may be implemented. Ultimately, the skills can also be deployed for inquiry-based learning of content in addition to learning inquiry skills.

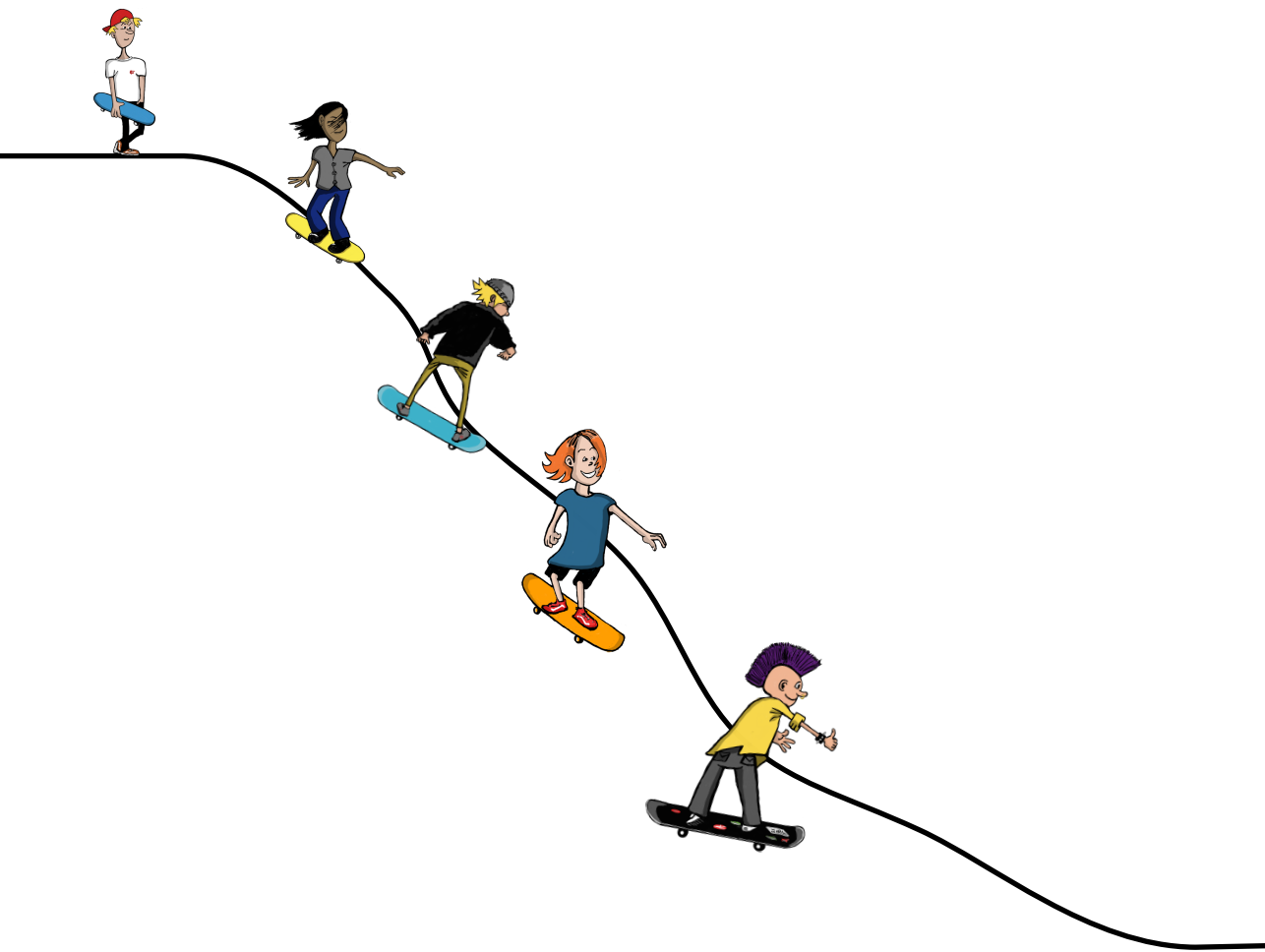
Furthermore, the 4C/ID system of Van Merriënboer et al. (1992) has proved to be useful in designing structured lessons for teaching inquiry skills. The task-centered approach provided ample opportunity to systematically incorporate important design principles such as explicit instruction and additional skills practice. The whole-tasks were not only pleasurable and motivating for students, but also provided the possibility to apply the inquiry skills in an integrated manner, supporting development of the skills.

To conclude, the present findings have provided additional information to the discussion of effective ways to teach inquiry skills to young students. In this study, the method of explicit instruction was not only compared with a baseline condition, but also with the implicit method of teaching skills. Therefore, this study provides a strong argument for implementing an explicit teaching method to promote and develop inquiry skills in primary science education.





on the acquisition of student's science inquiry skills in grades 5 and 6 of primary education



performance assessment as a  
**diagnostic tool**  
for science teachers

# ABSTRACT

Information on students' development of science skills is essential for teachers to evaluate and improve their own education, as well as to provide adequate support and feedback to the learning process of individual students. The present study explores and discusses the use of performance assessments as a diagnostic tool for formative assessment to inform teachers and guide instruction of science skills in primary education. Three performance assessments were administered to more than 400 students in grades 5 and 6 of primary education. Students performed small experiments using real materials while following the different steps of the empirical cycle. The mutual relationship between the three performance assessments is examined to provide evidence for the value of performance assessments as useful tools for formative evaluation. Differences in response patterns are discussed and the diagnostic value of performance assessments is illustrated with examples of individual student performances. Findings show that the performance assessments were difficult for grades 5 and 6 students but that much individual variation exists regarding the different steps of the empirical cycle. Evaluation of scores as well as a more substantive analysis of students' responses provided insight into typical errors that students make. It is concluded that performance assessments can be used as a diagnostic tool for monitoring students' skill performance as well as to support teachers in evaluating and improving their science lessons.

## Based on

Kruit, P. M., Oostdam, R. J., van den Berg, E., & Schuitema, J. A. (2018). Performance assessment as a diagnostic tool for science teachers. *Research in Science Education*.

DOI: [10.1007/s11165-018-9724-9](https://doi.org/10.1007/s11165-018-9724-9)



## 5.1 Introduction

With the increased attention towards the implementation of inquiry activities within primary science classrooms, educators have emphasized the importance of including assessments in science classroom practice (Duschl, Schweingruber, & Shouse, 2007; National Research Council (NRC), 2012). Information relating to students' development of science skills is essential for teachers to evaluate and improve their own education, as well as to provide adequate support to the learning process of individual students (Germann & Aram, 1996; Roth, 2014). In addition, including assessments of science skills is important because it ensures that these skills are taught (Harlen et al., 2012; Vogler, 2002). Performance assessments have been considered to be an alternative to paper-and-pencil tests for the assessment of science skills (Harmon et al., 1997; NRC, 2012; Shavelson, Baxter, & Pine, 1991). In a performance assessment students perform small investigations by interacting with real materials. Students' performance is evaluated on the basis of the actions they take and subsequently report on regarding their investigations. The present study explores and discusses the use of performance assessments as a diagnostic tool for formative assessment to inform teachers and guide instruction of science skills in primary education.

### **Skills and scientific inquiry**

Science skills - also referred to as "inquiry skills", "process skills" or "investigation skills" (Harlen & Qualter, 2009) - usually indicate a wide variety of activities related to planning and conducting investigations and interpreting results (Alonzo & Aschbacher, 2004; Gott & Duggan, 1995; Harlen & Qualter, 2009). In current literature, it is generally acknowledged that scientific inquiry activities in science classrooms should be based on the actual work of scientists (Lederman & Lederman, 2014; Pellegrino, 2014). Within the framework of K-12 science education, the NRC (2012) argues that students should learn about what actual scientists do when designing and carrying out inquiries. One of the aims is to understand how knowledge about issues such as health and environment is obtained and validated.

Authentic research involves three domains of activities in which scientists go back and forth: investigating, developing explanations and solutions, and evaluating data as evidence for the proposed theories and models (NRC, 2012). This implies that in performing a scientific inquiry, a wide variety of cognitive abilities are invoked. For example, different abilities are employed when handling a microscope than when identifying patterns in data.

Consequently, the consideration of different skill categories underlying the inquiry activities has been generally acknowledged (cf. Schraw, Crippen, & Hartley, 2006; Zohar & Dori, 2003). In particular, three categories which underlie performing a scientific inquiry may be involved: science-specific skills, thinking skills and metacognitive skills.

Science-specific skills can be classified as lower order thinking (Newmann, 1990) which is defined by knowledge recall, routine employment and simple application of rules (Goodson, 2000). These skills include practical skills such as taking measurements and using a microscope (Abrahams & Reiss, 2015), but relate to cognitive processes as well. That is, in performing a scientific inquiry, students must recall the facts and rules which are specific for the science domain and then apply this knowledge in the appropriate manner (Gott & Murphy, 1987; OECD, 2017). For example, converting data into tables and graphs can be regarded as a science-specific skill.

Thinking skills include the higher order skills, also frequently referred to as critical thinking (Moseley et al., 2005). Thinking skills involve manipulating complex information which consists of more than one element and has a high level of abstraction (Bloom, 1956; Flavell, Miller, & Miller, 1993). In a scientific inquiry, thinking skills are applied to make sense of the data and connect the observations to scientific theories (Osborne, 2015). These include, for example, formulating hypotheses, interpreting, analyzing, and evaluating data, drawing a conclusion, and classifying and inferring information (Moseley et al., 2005; Newmann, 1990; Pintrich, 2002; Zohar & Dori, 2003). Also, metacognitive skills such as planning, monitoring and evaluating task performance are considered key in promoting the quality of scientific inquiry (Schraw et al., 2006). For instance, evaluating their plan while performing the inquiry helps students to rethink what they are doing and adjust the plan if necessary (Michaels, Shouse, & Schweingruber, 2007). As argued by Kuhn (1997), the essence of scientific thinking is coordinating theory and evidence which specifically demands metacognitive skills.

For science education, the influence of content knowledge on skill development is generally considered to be of paramount importance (Duschl et al., 2007). Content knowledge is generally referred to as a conceptual understanding of facts, concepts, theories and principles (OECD, 2017). Many studies have shown that the level of content knowledge has substantial impact on skill development (Eberbach & Crowley, 2009; Kuhn, Schauble, & Garcia-Mila, 1992). Particularly, prior content knowledge influences the quality of students' inquiry performance when they generate hypotheses, make observations, evaluate evidence, and draw conclusions (Duschl et al., 2007; Millar & Driver, 1987).



### **Performance assessment**

As an alternative to standardized paper-and-pencil tests, performance assessments (PAs) are considered to be valid instruments when assessing students' science skills (NRC, 2012; Shavelson et al., 1991). In PAs, students perform small experiments by interacting with real materials. The small experiments in PAs are typically organized according to the different steps of the empirical cycle which include: (1) formulating a research question, (2) designing an experiment, (3) formulating a hypothesis, (4) measuring and recording data, (5) analyzing data, (6) formulating a conclusion, and (7) evaluating. As is generally acknowledged, scientists do not follow these steps linearly during actual research (NRC, 2012). However, the steps provide a structure that is recognizable for students which is particularly important for students in primary education who have little experience with scientific inquiry (Donovan, Bransford, & Pellegrino, 1999). Therefore, the different steps provide a suitable framework for systematic (formative) evaluation of students' science skills.

A PA generally consists of three components: a task, a response demand and a scoring system (Shavelson, Solano-Flores, & Ruiz-Primo, 1998). A PA can be considered to be a test on a particular topic which contains a set of items. The main characteristics of what defines a PA is that it is a complex task set in a context reflecting real-life experiences and in which different skills and knowledge are interconnected (Davey et al., 2015). The response demand may be verbal which requires observation measures in order to properly score it. It may also be written, for example, by means of a worksheet or a notebook. For measurement of skills involved in a scientific inquiry, a scientific report may be considered a valid reflection of authentic research since scientists use reports to communicate their findings. The nature of a scoring system depends on the type of task used. For example, for tasks in which students use worksheets to note results and write down answers to questions, a scoring rubric may be used to rate the students' responses.

PAs were implemented for large-scale testing such as in The Third International Mathematics and Science Study of TIMSS in 1995, and in the National Assessment of Educational Progress (NAEP) of 2009 (Britton & Schneider, 2014). Research up until now has been concerned with the limitations and advantages of implementing PAs for summative assessment. Previous studies showed low correlations between different PAs designed to measure the same science skills (Gott & Duggan, 2002; Pine et al., 2006). The main problem of using PAs for testing is that students perform differently on similar PAs from one occasion to the other (Ruiz-Primo, Baxter, & Shavelson, 1993; Solano-Flores, Javanovic, Shavelson, & Bachman, 1999). Various reasons for this occasion sampling variability have been put forward. For instance, the PAs generally differ in the context (the topic which reflects a real-life phenomenon) in which they are set. Students actual task performance

depends on the knowledge they have about the topic of the task as well as how well they are able to apply that knowledge (Klassen, 2006). This implies that, although the PAs call upon similar science skills, students perform differently for each PA due to the knowledge the student has of the particular topic of the PAs (Gott & Duggan, 2002; Shavelson et al., 1991). Accordingly, Ruiz-Primo et al. (1993) suggested that a reliable measurement of science skills may only be obtained by administering a substantial number of PAs.

Scoring of students' responses is generally considered a substantial challenge when implementing PAs. The scoring can either be based on directly observing the performance itself or on students' written responses which are evaluated after the event (Clauser, 2000). In science education, it is generally acknowledged that observing is not practical for large-scale and classroom testing (e.g., Klassen, 2006). Therefore, research has been concerned with evaluating students' written answers. An important advantage with written answers is that it lends the possibility of analyzing and scoring responses after the event has taken place (Schilling et al., 1990). Because PAs elicit skills similar to those that scientists apply when they perform a scientific inquiry and subsequently report the results, scoring the answers after the event is assumed to provide a valid indication of students' potential performance in real-life inquiry (Davey et al., 2015; Harmon et al., 1997; Kind, 1999).

However, it can be argued that a response format requiring extensive written answers demands a certain level of writing abilities. Harlen et al. (2012) argued that the response format may influence students' scores. The implication is that it may be more difficult to determine what exactly is being measured (Klassen, 2006; Stecher et al., 2000). On the other hand, in a study by Baxter and Shavelson (1994) addressing the exchangeability of observational and written scoring, results indicated that scoring written responses provides a satisfactory alternative to observation. It is nevertheless important that when developing PAs, attention should be paid to the "verbal demands of tasks" (Stecher et al., 2000, p. 154).

It has also been noted that scoring criteria and rubrics may be difficult to interpret by raters and therefore require extensive training to ensure that rating between raters and occasions be consistent (Davey et al., 2015). According to Clauser (2000), reliable rating is influenced by a number of different conditions such as the extent of detail of the scoring criteria and the level of training of raters. Rating may be improved when scoring rules are described in detail with examples of possible student answers. On the other hand, the scoring criteria may get too specific which limits generalizability across tasks (Messick, 1994). Also, raters may be influenced by students' handwriting and turns of phrase, or assess students' responses differently on different occasions. Although score variation caused by rater effects can be reduced considerably by thorough training (e.g., Ruiz-Primo





et al., 1993), the training and rating procedure is cost and labor-intensive (Davey et al., 2015; Klassen, 2006).

All of this said, it is still the case that, in contrast with paper-and-pencil tests, PAs have the important advantage of measuring skills more comprehensively because students actually apply these skills to a real-life scientific inquiry (Davey et al., 2015; Ennis, 1993). The issues of reliability previously discussed have less of an impact when used for formative assessment in the classroom (Harlen, 1999). In addition, as argued above, a major advantage of PAs is that students perform small experiments in which they systematically follow the various steps within the empirical cycle. This provides an opportunity to separate the various steps when determining students' performance levels. Furthermore, although a reliable rating of written responses is complicated due to the open format (Davey et al., 2015), teachers who score PA items find it considerably valuable to be required to focus on particular aspects of students' written answers rather than merely regarding them as right or wrong (Harlen, 1991). Aschbacher and Alonzo (2006) argued that notebooks can reveal students' thought processes which teachers can use to guide instruction. As a result, this use of PAs can provide ample opportunity to collect information on students' performance for not just summative but also for formative evaluation.

### **Formative assessment**

The primary purpose of formative assessment is to observe progress made and to collect information to guide subsequent teaching and learning (Harlen et al., 2012). Formative assessment elicits evidence of student performance and thus provides the teacher with information which can be used to modify teaching and classroom activities (Black, Harrison, Lee, Marshall, & Wiliam, 2004; Wiliam & Thompson, 2007). In a science classroom, the assessments may be spontaneously incorporated in the lesson by asking questions and starting discussions, or they may take the form of planned activities which are part of the curriculum (Loxley, Dawes, Nicholls, & Dore, 2013). Information on science skill acquisition can be gathered by observing students while prompting them to explore their ideas and reasoning. Also, students can be asked to communicate their thinking by using drawings and writing (Harlen, 1999).

When implementing PAs in the science classroom, students are provided with opportunities to use skills and are encouraged to think critically about their performance, which promotes students' learning. In particular, by structuring PAs to include the steps of the empirical cycle, more detailed information can be gathered on all aspects of a scientific inquiry. Teachers can provide adequate feedback on the students' work, engage students in

metacognitive discussion about the procedures applied in the PA and give them examples of a well-performed inquiry. Finally, teachers can provide students with the techniques and the language needed to perform a scientific inquiry (Davey et al., 2015; Harlen, 1999).

### **The present study**

The NRC (2014) has argued that assessments other than those currently used should be implemented in classrooms to reflect the contemporary vision of science education. An important aspect of the assessments is that they should be "... specific enough to be useful for helping teachers understand the range of student responses and provide tools for helping teachers decide on next steps in instruction" (NRC, 2014, p. 3). In general, in daily classroom practice, teachers will spend most of their time and effort on summative assessments rather than formatively assessing their students' progress (Black et al., 2004; Black & Wiliam, 2003). Even if they do implement formative assessments, this will generally not be aimed towards improving their teaching or the learning process of the students but mainly on "deciding the level of achievement" (Harlen, 1999, p. 137).

The aim of the present study is to explore and discuss in what way PAs can be used to provide teachers with diagnostic information to rate group or individual student performance. When developing PAs for summative assessment, their structure should also provide opportunities to use them for formative assessment in the classroom. This way, a more fine-grained picture of students' acquired skills may be obtained and used by the teacher to gain information about students' learning (Pellegrino, 2012). Therefore, in this study, the utility of the more specific information that may be obtained by structuring the PAs according to the different steps of the empirical cycle is discussed. Furthermore, the way PAs are structured and scored creates opportunities to monitor students' learning progress. This diagnostic information is not only important for teachers to improve their teaching but also to provide (individual) students with adequate feedback. As a result, the present study may add to the understanding of using performance assessments as a tool for formatively assessing students in science classrooms. The main research question within this present study is as follows: in what way can a PA be used as a diagnostic tool to evaluate students' progress and to guide instruction in science classroom practice? To answer this question, we discuss design principles of PAs and the corresponding scoring rubrics based upon the steps of the empirical cycle. Furthermore, we analyze and discuss the different levels of student performance on the three PAs: the mean scores, students' response patterns and illustrative examples of and trends in students' responses. Finally, we examine the relationship between the PAs per step to search for evidence for the usefulness of PAs for formative evaluation.



## 5.2 Method

### Sample

The responses on three PAs of 403 primary students (aged 10-12, 50.9% girls) were used. Of these students, 51.6% were in grade 5 and 48.4% in grade 6. The students were from 12 primary schools located in urban areas of the Netherlands. Schools were willing to participate on the basis of several pragmatic factors including permission of school authorities, interest of teachers, willingness to do something with science and available time.

The students in the present study were participants in an effect study with an experimental, a control, and a baseline condition. Students in the experimental condition received an intervention lasting 8 weeks in which regular explicit instruction in the use of inquiry skills was provided during regular science class. Explicit instruction involved the teacher clarifying the rationale behind these inquiry skills followed by examples and classroom discussions about how to apply the skills. Then, students performed a scientific inquiry in which they received guiding questions and specific feedback. In the lessons within the control condition, all aspects of explicit instruction were absent. Instead, skills were merely encountered and practiced while performing scientific investigations. Students in the baseline condition followed their regular science curriculum, meaning that they did not receive formal and structured instruction on inquiry skills during the intervention period. The PAs were implemented as summative measurement instruments.

### Description and development of the performance assessments

Three tasks were developed with topics suitable for grades 5 and 6 students: *Skateboard*, *Bungee Jump* and *Hot Chocolate*. Skateboard was based on the PA “Rolling Down Hill” (Ahlbrand, Green, Grogg, Gould, & Winnett, 1993). Bungee Jump and Hot Chocolate were based on tasks used in TIMSS (Martin et al., 1997).

All three PAs appertain to comparative investigations in which students explore the relationship between two variables (Shavelson et al., 1998). In Skateboard, students roll a marble (the “skateboard”) down a ruler (the “hill”) to investigate the relationship between the distance that the marble covers on the ruler (slope) and the distance the marble covers at the end of the ruler while pushing a paper wedge forward. Similarly, students investigate in Bungee Jump the changing length of a rubber band as additional weights (metal rings)

are added, and in Hot Chocolate, students examine the relationship between the amount of hot water and its rate of cooling.

Each PA was constructed according to the same template following the various activities (steps) of the empirical cycle (Table 5.1). In each PA the topic was introduced by a description of the context of the experiment. The context for Skateboard comprised a cartoon in which skateboarding children were wondering who would roll farther at the bottom of the hill. A cartoon for Bungee Jump represented children of different weights bungee jumping off a bridge and for Hot Chocolate a scenario was described of a cup of tea or hot chocolate that was still too hot to drink. The students' first task was to formulate a research question in line with the topic presented. In the following task, students were provided with a pre-formulated research question. Based on this research question, students were asked to design an experiment. This task feature ensured that the subsequent investigation designed by students was not contaminated by a flawed research question or that the designs would not become too divergent to be properly compared. The subsequent items followed the remaining steps of the empirical cycle and referred to the pre-formulated research question (see also Table 5.1).

University lecturers in the field of biology and physics education assessed the items regarding clarity of formulation, activity to be measured and suitability for young students. Minor adjustments were then made to the items. To provide students with additional scaffolding, students were asked to formulate a hypothesis after designing the experiment whereas it is typically the other way round.

Prior to implementing the PAs as summative assessments in the effect study, preliminary versions of all three PAs were piloted with 70 grades 5 and 6 students. Based on the outcomes, several adjustments were made regarding the formulation of instructions, questions and task structure.

### **The scoring rubric**

To obtain a fine-grained picture of the students' ability to perform a scientific inquiry, a rubric was developed for scoring all 14 items of the PAs. Since generally speaking, existing rubrics are specifically designed to match a particular task, a new scoring rubric for the PAs was developed.

First, the activities were operationalized by specifying what a student's response should entail. The elements of the specifications were derived from resources in which goals and learning progressions for science skills are described (e.g., Next Generation Science Standards (NGSS), 2013; <https://pals.sri.com>). For example, for designing an



experiment, the following goal was formulated for the scoring rubric of the PAs used in this study:

The goal is that students learn to construct a design consisting of several elements. The design is aimed at finding a relationship between two variables and is described in a structured manner, which entails that the steps are at least in chronological order. There is sufficient information to replicate the experiment.

Next, the criteria for different levels of proficiency were formulated as detailed descriptions of the elements required to appear within students' answers. University lecturers in the field of biology and physics education were employed as content experts to assess the criteria for awarding points to the different levels of proficiency of possible answers. An answer containing more elements is considered to demonstrate a higher level of ability. Depending on the number of elements, more points are awarded (see the score column in Table 5.1). Primary school teachers then reviewed the criteria to determine its feasibility for grades 5 and 6 students.

Students' responses obtained from the pilots were used to evaluate and adjust the scoring criteria. Characteristic responses were added as examples to illustrate the different levels of proficiency. The criteria descriptions and examples of all three PAs were equivalent and differed only in their context-specific elements.

Within each PA items were assigned to one of the steps of the empirical cycle (Table 5.1). For some steps, more than one item was assigned. For example, the step "measure and record data" included two items while four items were assigned to the step "formulate a conclusion". Scores for each step were obtained by summing up the scores of the assigned items. As a result, the 14 items were reduced to separate scores for each of the seven steps of the empirical cycle.

**Table 5.1**  
*blueprint of items of the performance assessments*

item	description of activities	step empirical cycle	score
1	Formulate research question	Research question	0-1-2
2	Design experiment: Description of experimental set-up Description of how results will be noted	Design	0-1-2-3 0-1-2
3	Formulate hypothesis	Hypothesis	0-1-2
4	Note results in a table students make themselves	Measure & record	0-1-2-3
5	Make a graph: Axes Line graph	Measure & record	0-1-2 0-1-2
6	Interpret results by relating two variables	Analyze	0-1-2
7	Extrapolate results	Analyze	0-1-2
8	Draw conclusion about relationship	Conclusion	0-1-2
9	Formulate support for conclusion	Conclusion	0-1-2
10	Relate hypothesis to conclusion	Conclusion	0-1-2
11	Identify differences between plan and execution of experiment and explain reason(s) of differences or in absence of differences, give suggestions to improve the experiment	Evaluate	0-1-2
12	Give suggestions to extend the experiment	Evaluate	0-1-2
13	Draw conclusion related to the context	Conclusion	0-1-2
14	Formulate learning gains about inquiry	Evaluate	0-1-2
Maximum score			34

*Note: maximum score per step: Research question: 2; Design: 5; Hypothesis: 2; Measure & record: 7; analyze: 4; Conclusion: 8; Evaluate: 6*

**Scoring procedure**

All students’ hand-written answers to the PAs were scored after having been transcribed into typed text and grouped by item. Raters were trained to interpret the criteria as it was intended and to award points to students’ responses in a consistent manner. During training sessions, the scores of each item were compared separately and interpretations of the criteria and students’ responses were discussed. This enabled the fine-tuning of the criteria. After establishing satisfactory interrater reliability for the total score of a random sample of an average of 12% of the responses (varying from .82 to .92, single-measures ICC, two-way random, absolute agreement), administered tests were randomly distributed to be



scored by individual raters. Finally, for each rater, stability of scoring was estimated. This ranged from .81 to 1.00. To provide more detailed information on the rating process, the interrater reliability per individual item is shown in Table 5.2. The low correlations of item 3 in all PAs indicate that raters may not have had a common understanding of the formulation of a hypothesis. On average, the rating process of a PA took 20 minutes per student.

**Table 5.2**  
*intra-class correlations (a) of raters after training per item*

		Skateboard	Bungee Jump	Hot Chocolate
item 1	Formulate research question	.83	.74	.88
item 2	Design experiment	.74	.69	.82
item 3	Formulate hypothesis	.56	.61	.65
item 4	Make a table	.86	.88	.81
item 5	Make a graph	.89	.82	.90
item 6	Interpret results	.92	.72	.57
item 7	Extrapolate results	.88	.73	.75
item 8	Draw conclusion	.86	.72	.85
item 9	Formulate support for conclusion	.77	.60	.61
item 10	Relate hypothesis to conclusion	.78	.67	.69
item 11	Identify differences between plan and execution	.59	.59	.77
item 12	Give suggestions to extend the experiment	.80	.83	.88
item 13	Draw conclusion related to the context	.53	.51	.76
item 14	Formulate learning gains	.88	.89	.83

### Administration procedure

Individual research assistants administered the PAs in groups of four to a maximum of eight students outside of the regular classroom. It took about 45 minutes to complete the test administration of one PA. Each research assistant received extensive training and followed detailed protocols for test administration. Each student completed three PAs on two different occasions with a time interval of 8 to 10 weeks. On the first occasion, all students completed the same PA (Skateboard). On the second occasion administration of the two other PAs (Bungee Jump, Hot Chocolate) was randomly rotated. About half of the students completed the PA Bungee Jump, while the other half completed Hot Chocolate and vice versa. This rotation for the second occasion made it possible to determine whether both PAs map student performance in the same way, allowing us to conclude that they are equivalent diagnostic tools.

# 5.3 Findings

## Descriptive statistics

Table 5.3 presents the mean scores and standard deviations of the PAs per step. To facilitate comparison between the steps, the total scores for each step were converted into a standard scale ranging from 0 (lowest) to 10 (highest). In Table 5.3 and in most of the following tables, the scores of Skateboard are shaded gray to emphasize that this PA was administered on a different occasion than the other two PAs. The mean scores on step level indicate differences between steps in terms of difficulty. For instance, designing an experiment seems in general to be more difficult than formulating a hypothesis. Differences are also visible between PAs. For example, in Bungee Jump and Hot Chocolate the mean scores for “measure and record” are higher than those fosterin Skateboard.

**Table 5.3**  
*means and standard deviations on converted standard scales (0-10) for the different steps of the empirical cycle (N= 403)*

	Skateboard		Bungee Jump		Hot Chocolate	
	Mean	SD	Mean	SD	Mean	SD
Research question	2.47	3.82	5.97	4.04	6.46	3.32
Design	2.64	2.06	3.31	2.51	3.83	2.49
Hypothesis	5.32	3.74	4.85	3.52	4.08	3.72
Measure and record data	2.97	2.63	4.47	2.75	4.82	2.74
Analyze	2.93	2.80	3.36	3.09	2.99	2.97
Conclusion	2.96	2.26	2.82	1.98	2.93	2.06
Evaluate	3.10	2.03	3.40	2.12	3.25	2.05

*Note: the gray-shaded column represents the scores on the first occasion*

Overall, scores of the steps in all PAs show relatively low means indicating that the PAs were in general difficult for grades 5 and 6 students. The highest score is a 6.46 for formulating a research question. However, the large standard deviations reflect a high amount of variation within the sample.

In Table 5.4 the relationship between the PAs per individual step is displayed. Although significant, most correlations are small to medium with the exception of the step of “measure and record data” between Bungee Jump and Hot Chocolate which can be considered large ( $r = .83$ ) (Cohen, 1988). These moderate correlations may have been caused by task differences. Although the PAs were similar in structure and items, the topics





**Table 5.4**  
**correlations (Pearson's  $r$ ) between the PAs per step of the empirical cycle ( $N = 403$ )**

	Skateboard / Bungee Jump	Skateboard / Hot Chocolate	Bungee Jump / Hot Chocolate
Research question	.15**	.25*	.24*
Design	.22*	.24*	.44*
Hypothesis	.06	.17**	.19*
Measure and record data	.37*	.33*	.83*
Analyze	.25*	.08	.24*
Conclusion	.32*	.16**	.34*
Evaluate	.29*	.29*	.39*

\* correlations are significant at  $p < .001$  (2-tailed)

\*\*  $p < .05$

between the PAs varied. As previously discussed, familiarity with the topic can influence application of skills considerably, resulting in variations between PAs within student performance.

Furthermore, these correlations between PAs as presented in Table 5.4, show that for most steps, correlations between Bungee Jump and Hot Chocolate are slightly larger than correlations of either of these PAs with Skateboard which was administered 8 weeks before the other two. Several reasons may account for these results. In the 8 weeks preceding administration of Bungee Jump and Hot Chocolate, about two third of the students had received lessons in which they had been performing small investigations similar to the PAs. In addition, all students had experience with the Skateboard experiment on the first testing occasion. As a result, students were more familiar with the testing format on the second occasion which may explain the difference in performance.

### Response patterns

Tables 5.5 to 5.11 show in more detail how students performed in each step of the empirical cycle by presenting the response pattern of scores. In each table, the scores of Skateboard are shaded gray to emphasize that this PA was administered on a different occasion than the other two PAs. To demonstrate how the response patterns may provide diagnostic information to teachers, the trends in the student responses per step will be discussed in more detail and illustrated with examples.

Formulating a research question

Scores presented in Table 5.5 for formulating a research question clearly show a shift from the majority of students scoring 0 points in the PA Skateboard to more than 75% of students scoring 1 or 2 points in PAs of the second occasion.

The research questions formulated by students awarded with 0 points in Skateboard were in general either unrelated to the goal of the experiment of finding a relationship between two variables ("What happens when the marble does not roll against the paper wedge?") or were impossible to investigate ("Why do Jake or Ying go faster?"). In the PAs on the second occasion more students were accurately able to formulate a research question which described the relationship between the two variables. For instance, "Does the rubber band stretch more when people are heavier?" in Bungee Jump or "Does the amount of water influence the cooling rate?" in Hot Chocolate.

Interestingly, for Hot Chocolate, the research questions frequently addressed the issue of what makes hot drinks turn cold ("How does the drink cool faster: by blowing or just waiting?" or "Can a hot drink cool down in different ways?"). A possible explanation is that students may have been more familiar with the topic of the cooling of hot drinks than with skateboarding or bungee jumping.

Table 5.5  
response pattern of PA scores for the step of formulating a research question (N = 403)

score	Skateboard		Bungee Jump		Hot Chocolate	
	n	%	n	%	n	%
0	271	67.2	100	24.8	47	11.7
1	65	16.1	125	31.0	191	47.4
2	67	16.6	178	44.2	165	40.9

Note: the gray-shaded column represents the scores on the first occasion

Designing an experiment

Students' combined scores on the two items representing the step of designing an experiment (Table 5.6) are spread in the lower regions of scores.

Typically, low overall scores were mainly the result of students having failed to describe how they intended to communicate their results. Also, their descriptions were in general not very specific ("Attach the weights and see how far it stretches."), or they presented a design that did not relate to the research question ("I will see how fast the marble goes. We need cubes, a card and a ruler."), or they paid too much attention to details which were not relevant ("1. Put the cube on one side; 2. Put the green paper on the



**Table 5.6**  
**response pattern of PA scores for the step of designing an experiment (N = 403)**

score	Skateboard		Bungee Jump		Hot Chocolate	
	n	%	n	%	n	%
0	81	20.1	66	16.4	47	11.7
1	184	45.7	154	38.2	120	29.8
2	83	20.6	83	20.6	112	27.8
3	41	10.2	65	16.1	81	20.1
4	12	3.0	23	5.7	30	7.4
5	2	0.5	12	3.0	13	3.2

*Note: the gray-shaded column represents the scores on the first occasion*

other side; 3. Put the ruler on the cube; 4. Put the green paper on the card; 5. Roll the marble.”). Designs awarded with higher scores were in general more extensive descriptions and included relevant details, such as the number of planned measurements (“Needed: 8 rings, clipboard, rubber band, a paper clip. First time measuring I put 4 rings on the paperclip, second time measuring 3 rings and third time 1 ring. Every time I measure how far it goes down. I note the results in a table.”).

### Formulating a hypothesis

To support the formulation of a hypothesis, students were provided with a sentence starter: “I think that ..., because ...” . As shown in Table 5.7, for each PA the scores for formulating a hypothesis are spread in similar ways with most students scoring not higher than 1 point.

In general, most students were able to formulate a prediction and were awarded with 1 point, but they typically failed to substantiate their prediction (“I think the rubber band will stretch more with a heavier person, because the person is heavier”) or (referring

**Table 5.7**  
**response pattern of PA scores for the step of formulating a hypothesis (N = 403)**

score	Skateboard		Bungee Jump		Hot Chocolate	
	n	%	n	%	n	%
0	100	24.8	106	26.3	155	38.5
1	177	43.9	203	50.4	167	41.4
2	126	31.3	94	23.3	81	20.1

*Note: the gray-shaded column represents the scores on the first occasion*

to the research question: “I think it is true, because the heavier, the more it stretches.”). Students with full scores provided an explanation for their prediction, for instance “I think that the heavier thing goes down, because the rubber band needs more strength to hold the heavier thing up.” In some instances, students managed to use more abstract concepts, such as “I think that it will stretch more, because more mass, more weight, more gravity.” An interesting finding is the relatively low interrater reliability score (see Table 5.2) in each PA of this particular step. Apparently, the raters found it difficult to distinguish between a well-formulated hypothesis and a poorly formulated hypothesis.

### Measuring and recording data

The step of measure and record data included making a table for noting the results and drawing a line graph. The pattern of the scores presented in Table 5.8 show that students performed better in the second occasion PAs when students in the experimental and control conditions had more experience with graphs. The response patterns further indicate that students differ considerably in their ability to measure and record data. For instance, around 12% of the students did not succeed at all in scoring points for this step, but the same proportion of students scored as many as 6 or 7 points.

The most common approach of recording measurements was in a more or less structured way (see Figure 5.1). Full credits were only awarded if a student recorded the data in a table indicating rows and columns (Figure 5.2).

The graphs in each PA were pre-labeled to offer students some support. In Skateboard many students made a bar graph instead of a line graph, indicating they did not have the specific knowledge on the concept of a line graph (Figure 5.3). Furthermore, many

**Table 5.8**  
*response pattern of PA scores for the step of measuring and recording data (N = 403)*

score	Skateboard		Bungee Jump		Hot Chocolate	
	n	%	n	%	n	%
0	109	27.0	51	12.7	44	10.9
1	69	17.1	37	9.2	29	7.2
2	77	19.1	66	16.4	63	15.6
3	47	11.7	75	18.6	63	15.6
4	53	13.2	66	16.4	73	18.1
5	28	6.9	52	12.9	69	17.1
6	17	4.2	50	12.4	54	13.4
7	3	0.7	6	1.5	8	2.0

*Note: the gray-shaded column represents the scores on the first occasion.*

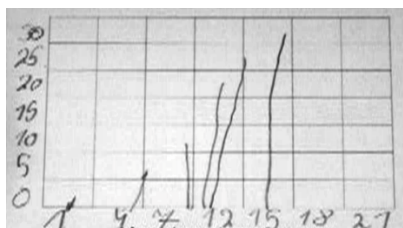


1: 12 cm  
2: 12,5 cm  
4: 13,5 cm

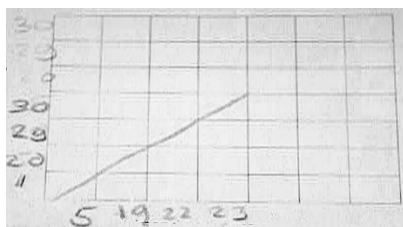
**Figure 5.1**  
*noted results of measurements by a student in Skateboard*

aantal gewichtjes	1	2	3	4	5	6	7	8
aantal cm dat het elastiek uitrekt	22	23	23.5	24	24.5	26	27	28.5
	cm	cm	cm	cm	cm	cm	cm	cm

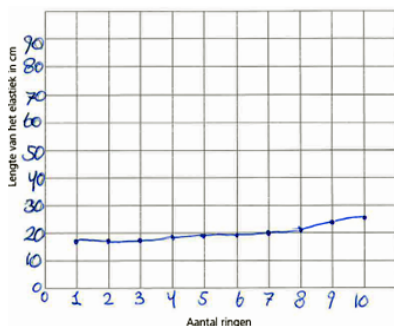
**Figure 5.2**  
*table awarded with full credits made by a student in Bungee Jump*



**Figure 5.3**  
*example of a bar graph made by a student in Skateboard*



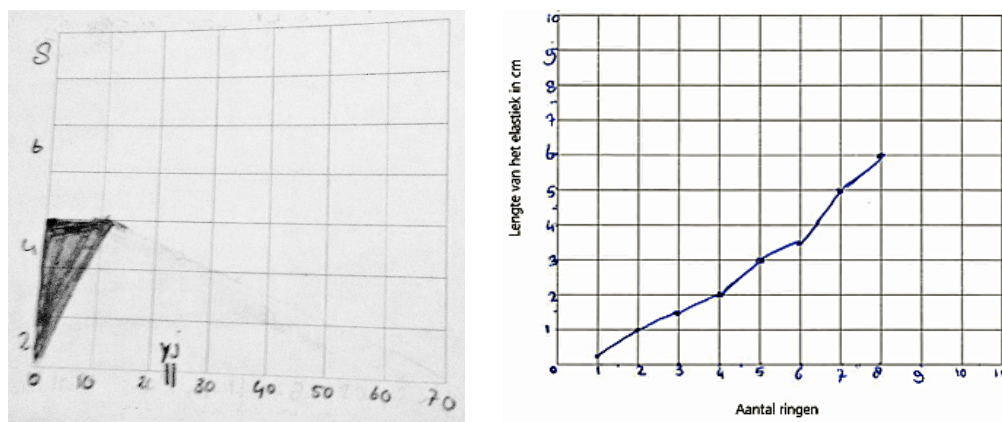
**Figure 5.4**  
*example of a graph with the units not inserted properly made by a student in Skateboard*



**Figure 5.5**  
*example of a graph with wrong scaling of units made by a student in Bungee Jump*

students had difficulty to insert the units and the proper interval of units on both axes (Figure 5.4) and using units with the right scaling resulting in graphs showing too little change (Figure 5.5). However, some students were able to draw quite sophisticated graphs of their data, and one particular student even included a legend.

The examples provide information on how instruction on making graphs may improve scores for this particular step in the empirical cycle. For instance, students in the explicit condition received instruction on the purpose of different types of graphs and on how to decide on the units to put on the axis. To illustrate, Figure 5.6 shows the progress in drawing graphs of one particular student in Skateboard and after 8 weeks in which the student had received instruction on drawing graphs in Bungee Jump.



**Figure 5.6**  
*example of progress in drawing a graph of one of the students (Skateboard, left, and Bungee Jump, right)*

### Analyzing data

Finally, the steps of analyzing data, formulating a conclusion and evaluating show more or less similar patterns of scores between the three PAs. For analyzing data (see Table 5.9), full credits were only awarded if students explicitly mentioned the two variables and their relationship and if the conclusion was consistent with their own measurements. For instance: "If more rings are added, the rubber band gets longer." or "As more rings are added, it gets heavier so the rubber band stretches more." And for Skateboard: "The higher up the marble starts, the farther it rolls."

Students were in general able to describe the relationship between the two variables. However, although many students succeeded in describing the connection between variables, this relationship was not always supported by their own measuring and recording of data. Based on logical thinking, interdependence between variables was assumed by students, even if their own data did not match this reasoning. It was also regularly found that students indicated a relationship but failed to describe the



**Table 5.9**  
**response pattern of PA scores for the step of analyzing data (N = 403)**

score	Skateboard		Bungee Jump		Hot Chocolate	
	n	%	n	%	n	%
0	153	38.0	141	35.0	165	40.9
1	86	21.3	78	19.4	68	16.9
2	118	29.3	112	27.8	109	27.0
3	34	8.4	48	11.9	48	11.9
4	12	3.0	24	6.0	13	3.2

*Note: the gray-shaded column represents the scores on the first occasion*

relationship properly. For example, “More weights is more centimeters.” In Skateboard, students often referred to the speed of the marble as a reason for rolling farther away at the end of the ruler, such as “The higher it is, the faster it goes down.”

In extrapolating the results - also an element of analyzing results - much variation of students’ responses existed. No points were awarded if students simply mentioned an outcome. Students sometimes added an explanation but not substantiated with data. For instance, “I think 170 cm because it builds up much speed because of the length.” The following answer was awarded with full credits because the student had found a linear relationship between the two variables and used his own measurements: “2 meters far because if the slope is 20 cm it goes 10 cm far and two meters if 10 times as much as 20 cm, so  $10 \times 10 = 100$  and that is  $100 \text{ cm} = 1 \text{ m}$ .”

### Formulating a conclusion

The step of formulating a conclusion combined several aspects. First students were asked to give an answer to the research question and to support their answer with an explanation explicitly based on their own data. Then, students were required to relate the conclusion to the hypothesis as well as to the context of the PA. Table 5.10 shows how students’ scores were spread.

In all three PAs approximately one third of the students were able to formulate a correct conclusion (“The higher you stand on the hill, the longer you can roll.”) but only an average of 9% of students achieved the maximum score of 2 points by supporting their conclusion with data.

When students were asked to relate the results to the specific context of the investigation, around 44% of the students in both Skateboard and Bungee Jump, and 25% of students in Skateboard formulated a conclusion which related to the context (“With the

**Table 5.10**  
*response pattern of PA scores for the step of formulating a conclusion (N = 403)*

score	Skateboard		Bungee Jump		Hot Chocolate	
	n	%	n	%	n	%
0	79	19.6	62	15.4	60	14.9
1	68	16.9	84	20.8	79	19.6
2	75	18.6	81	20.1	88	21.8
3	70	17.4	93	23.1	72	17.9
4	52	12.9	44	10.9	63	15.6
5	38	9.4	27	6.7	28	6.9
6	18	4.5	12	3.0	9	2.2
7	3	0.7	0	0	4	1.0
8	0	0	0	0	0	0

*Note: the gray-shaded column represents the scores on the first occasion*

heavier person the rubber band stretches more.”). In Bungee Jump and Hot Chocolate, hardly any students were able to substantiate their conclusion by referring to the data. Remarkably however, 18% of students scored full credits for this particular item in Skateboard. During unstructured conversations after having completed the PAs on the second occasion, students told the researcher that they felt they were repeating their answers and therefore did not bother explaining their conclusion again, especially since it was their second and third PA.

### Evaluating

The scores regarding the final evaluating step show that only three students obtained full credits (see Table 5.11). In particular, an average of 9% of the students was able to give suggestions to extend the experiment by describing which relationship they would like to investigate (“To see whether the height on the hill also influences speed”). Most students receiving 1 point suggested additional experiments (see Table 5.1, item 12), but did not add an explanation (“I would do the experiment with longer distances”).

Furthermore, about 80% of the students failed to formulate their learning gains resulting from the experiment in response to item 14 (see Table 5.1). For example, although students referred to having learned about the relationship between the variables which is considered a learning gain related to content, they did not answer the explicit question regarding what they had learned about performing an inquiry. However, the answers of the students who had received 1 or 2 points on item 14 were diverse and interesting. For instance: I have learned ...”that there are more ways to start an





**Table 5.11**  
**response pattern of PA scores for the step of evaluating (N = 403)**

score	Skateboard		Bungee Jump		Hot Chocolate	
	n	%	n	%	n	%
0	74	18.4	49	12.2	57	14.1
1	75	18.6	94	23.3	89	22.1
2	121	30.0	114	28.3	120	29.8
3	101	25.1	95	23.6	96	23.8
4	31	7.7	42	10.4	36	8.9
5	1	0.2	7	1.7	4	1.0
6	0	0	2	0.5	1	0.2

*Note: the gray-shaded column represents the scores on the first occasion*

experiment", "you get a better answer when you try it yourself", "that measuring and being able to calculate is very important", "how to perform an experiment by taking all steps", "the reason for drawing a graph", and variations of "that you have to work very precisely/neatly."

## 5.4 Discussion

The present study aimed to answer the question whether a performance assessment can be used as a diagnostic tool to evaluate students' progress and to guide instruction in science classroom practice. Findings show that PAs have potential as a diagnostic tool for monitoring students' performance of skills, hence adjusting instruction and activities to enhance learning. In particular, the structuring of PAs by assigning items to the different steps of the empirical cycle, combined with the extensive descriptions of performance expectations for each item, has shown to be useful in evaluating students' responses.

This structured approach makes it possible for teachers to analyze the responses of students on various levels and use the findings to adjust their instruction. For instance, the means per step provide information on how students perform as a group at the classroom level. Response patterns per step indicate that there is considerable variation, indicating that the measurements are suitable for mapping individual differences. In particular, the response patterns of the steps reveal where students show particular difficulty and in which steps students perform more successfully compared with the average classroom performance. This information will help the teacher to obtain an overall picture of how students are progressing and subsequently adjust instruction as well as make informed decisions regarding the choice of science activities. Finally, looking at students' responses in more detail provides insight into the common mistakes the students make and reveals to some extent students' thinking processes (Davey et al., 2015). As a result, teachers are able to not only adjust their instruction to remedy shortcomings but also give specific feedback to individual students (Black et al., 2004; Harlen, 1999).

Similarly, the rubric may have additional value for implementing PAs as a diagnostic tool. The results of analyzing interrater reliability and consistency of scoring suggest that the scoring rubric can be used effectively by trained raters. In particular, the high consistency of scoring shows that the raters were able to apply the rubric to score students' written answers reliably. This implies that for teachers it is possible to assess students' answers to different PAs consistently over time by using the rubric.

In addition, the rubric can play an important role in the professional development of science teachers. Because of the extensive description of the learning objectives, of which teachers do not always have a clear understanding (Aschbacher & Alonzo, 2006), and the different levels of proficiency, teachers may become more explicitly aware of the learning objectives of scientific inquiry, while at the same time gaining better understanding of the skills they are scoring. Emphasis on scoring is particularly important, since in the

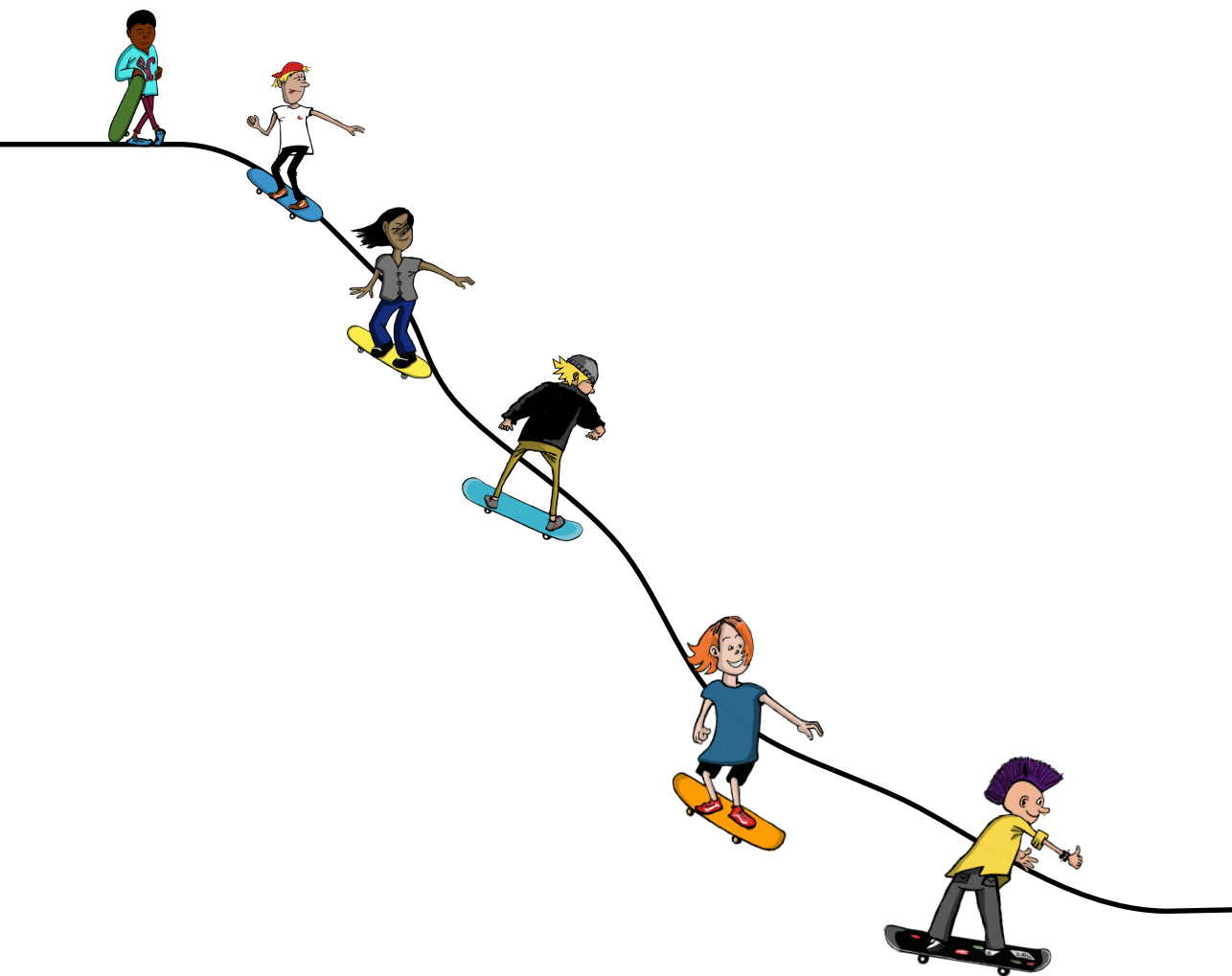


Netherlands only in 16% of primary schools (grades 4-6) the progress of students' learning of science is monitored by teachers (Inspectorate of Education, 2015).

The diagnostic value of PAs may also prove to have more value than just of an assessment tool. Davey et al. (2015, p. 9) state that "A good assessment task is a good teaching task and vice versa.", which stresses the importance of alignment between curriculum and assessment. Because of the structuring of the PAs in steps of the empirical cycle, a PA can be split and administered in more than one lesson as a component of a regular science lesson. In this way, teachers can monitor performance through the workbooks of students which provides the opportunity to give feedback during the course of several lessons (Harlen, 1999). Furthermore, it addresses the problem of the limited time assigned for science instruction in most primary schools (Martin, Mullis, Foy, & Stanco, 2012; NASEM, 2015). Finally, adding the rubric as part of the instruction may also create awareness and understanding of the science skills and students' own learning process, which is perhaps the most important purpose of formative assessment (Harlen, 1999).

There is one limitation that should be addressed when implementing the PAs. The response patterns of the scores vary between the PAs as revealed by the low and moderate correlations between PAs per step. This may be attributed to the different topics used for the PAs. Students may find one topic more interesting or less difficult than another. Teachers may choose PAs with topics with which students are familiar (either by own experience or being taught about the content of the PA topic ) or in which they are interested. In addition, inconsistencies in rating may have influenced variation between steps of the PAs (Ruiz-Primo et al., 1993). As discussed above, although interrater reliability was high on total scores as well as on most individual items, a few items proved more difficult to score such as formulating a hypothesis. This suggests that although formatively evaluating on step level is useful for teachers to monitor (a group of) students, the scores on step level may not be reliable enough for summative assessment. For reliable summative assessment, more items per step should be included or more PAs with a range of different topics should be used.

In summary, this study shows that a PA structured according to the steps of the empirical cycle, is a useful tool to inform teachers on students' science skills at a detailed level. It does not require intensive preparation to administer in a science classroom and fairly simple materials can be used. Implementation of the PAs need not necessarily be limited to grades 5 and 6 but may also be used for students in grades 7 or higher. Professional development of teachers should address the learning objectives for scientific inquiry and how to use students' responses for evaluation. Future research will have to determine to what extent science teachers will be willing and able to implement the PAs as a diagnostic tool in their classroom.



## summary and general discussion

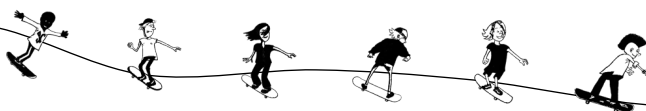
The aim of the present research project was to examine the effects of instruction methods facilitating the acquisition of science skills of primary school students of grades 5 and 6. To assess the effects, measurement instruments for reliable and valid evaluation of the acquisition of science skills were developed. Accordingly, the following five research questions were addressed:

1. What are science skills and how can they be operationalized?
2. What are crucial components of an instructional design for teaching science skills?
3. How can students' ability in performing scientific inquiry be validly and reliably measured?
4. What are the effects of explicit instruction on students' acquisition of skills in scientific inquiry?
5. What is the added value of performance assessments as a diagnostic tool to guide instruction in science classroom practice?

In the preceding chapters, results of various sub-studies were discussed and answers were formulated to the five above-mentioned central research questions. In this concluding chapter, we give a brief summary of all the findings and relate the results to the theoretical frameworks with regard to learning and teaching science skills. Subsequently, we examine the limitations of the different studies and discuss suggestions for future research. Finally, implications for educational practice are discussed.

### **Brief overview of the research project**

The studies presented in this thesis were focused on the acquisition and measurement of science skills of students in primary education. The central aim of the studies presented in chapters 2 and 4 was to improve understanding of the teaching and learning of science skills. The main aim of the research presented in chapters 3 and 5 was to explore the construction of different assessment instruments for summative as well as formative evaluation. The findings of the study reported in chapter 2 provided a categorization of various aspects of science skills and a teaching model. This was used to design lessons aimed at acquisition of science skills and in chapter 3 to construct instruments to measure the acquisition of students' science skills. Furthermore, the effects of these lessons were explored and measured with these assessment instruments in chapter 4. In chapter 5, the responses of students and the potential of performance assessments as a diagnostic tool for teachers was further explored.



## 6.1 Summary

### Operationalization of science skills

In chapter 2 we addressed the first research question by discussing the definition and operationalization of science skills. Despite their prominence, science skills remain a rather “ill-defined domain” (Gobert & Koedinger, 2011). In most curriculum frameworks science skills are defined by the activities which are intended to reflect the work of actual scientists (Lederman & Lederman, 2014). The rationale is that knowing and experiencing how scientists work will enable students to develop an idea of the methodological toolbox of a scientist. The underlying assumption in many teaching programs is that by carrying out a scientific investigation, students will learn science skills naturally and at the same time develop an understanding of how scientists work. Within that context, Osborne (2014) argues that engaging in scientific practice can improve the quality of students’ learning. However, the way scientists work is different from the way students learn. Students in primary education are still novices with regard to scientific inquiry. Science skills need to be acquired in a systematic manner (Metz, 2011). When designing effective instructional methods with the purpose of stimulating the development of science skills, it is essential to acknowledge the cognitive demands underlying these science skills. We argued that three different skills underlie the general concept of science skills. These are defined as science-specific skills, thinking skills and metacognitive skills.

In the context of performing a scientific inquiry, science-specific skills refer to the ability to apply procedural and declarative knowledge which is needed for properly setting up and conducting an inquiry (Gott & Murphy, 1987). Examples of these skills include taking measurements, organizing data into tables, making graphs, or using measurement devices. Science-specific skills are classified as lower order thinking (Newmann, 1990) or reproductive thinking (Maier cited in Lewis & Smith, 1993), and are characterized by knowledge recall, comprehension, the routine employment of rules, and simple application (Goodson, 2000). Science-specific skills defined as such include the practical skills as discussed by Abrahams and Reiss (2015), but they pertain to cognitive processes as well.

Thinking skills include the higher order skills, also frequently referred to as critical thinking (Moseley et al., 2005). Thinking skills involve manipulating information that is in nature complex because it consists of more than one element and has a high level of abstraction (Bloom, 1956; Flavell, Miller, & Miller, 1993). In a scientific inquiry, thinking skills are applied to make sense of the data and to connect the observations to scientific theories

(Osborne, 2015) such as formulating hypotheses, making inferences from different sources of data, identifying features and patterns in data, or drawing a conclusion (Millar & Driver, 1987; Pintrich, 2002; Zohar & Dori, 2003).

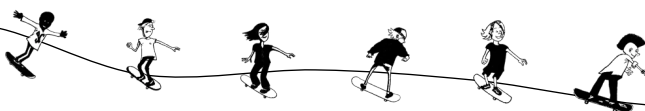
Metacognitive skills include planning, monitoring and evaluating task performance (Flavell et al., 1993). These skills influence the quality of the scientific inquiry process which in particular demands self-regulation and use of metacognitive strategies (Schraw, Crippen, & Hartley, 2006). What distinguishes metacognitive skills from thinking skills is that they involve active executive control of the mental processes (Goodson, 2000) or the “thinking about thinking” (Kuhn, 1999; Kuhn & Dean, 2004, p. 270).

Finally, we discussed the influence of content knowledge on skill development and performance. Content knowledge is most often referred to as conceptual understanding of facts, concepts, theories and principles (OECD, 2017). Previous studies have shown that content knowledge is, to a certain extent, a prerequisite for skill development (e.g., Eberbach & Crowley, 2009; Kuhn, Schauble, & Garcia-Mila, 1992). Different levels of content knowledge can result in significant differences in skill performance (French & Buchner, 1999). Even when the level of cognitive abilities is supposed to be a limiting factor for a given individual such as a young student, it is still possible to become an expert in a specific subject area (for example “dinosaurs”) and subsequently perform better in problem solving tasks compared to adults who know less about the subject (Glaser, 1984).

## Components of an instructional framework

To answer the second research question of identifying the crucial components of an instructional design for teaching science skills, we developed an instructional framework for teaching science skills based on the operationalization of science skills into three different underlying skills (or subskills) (chapter 2). Grounded on the design principles of this framework, a series of eight lessons was constructed, piloted and used for the intervention of the quasi-experimental pretest-posttest study (chapter 4).

Skills for scientific inquiry are usually taught by instructional methods primarily based on learning by doing (Duschl, 2008; Roth, 2014) despite evidence suggesting that more explicit teaching methods and strategies may be more effective (Klahr & Nigam, 2004; Lazonder & Harmsen, 2016). Most teachers focus on only the practical aspects of scientific inquiry which results in the disregard of the wide variety of cognitive abilities called upon in scientific investigations. Due to limited experience and instruction, students in primary education often lack sufficient mastery of strategies and knowledge to effectively use and





apply the skills to a scientific inquiry in an integrated way. In addition, the working memory capacity of students who are novices at performing a scientific inquiry may limit their ability to conduct a complex task. For this reason, we argued that an instructional framework based upon a cognitive approach aimed at acquiring science skills by means of an explicit instruction method may support students' learning process more adequately than an approach based on learning by doing, and offers educators and teachers guidance in designing and conducting lessons.

Explicit instruction aims to make students explicitly aware of the skills they should learn and apply. Making students explicitly aware of the strategies and skills that they are applying to a particular task leads to enhanced mastery which in turn may facilitate transfer, which is considered an indication of more robust learning. Near-transfer can generally be defined as the application of skills to tasks within a particular knowledge domain or with a common structure. In this study, explicit instruction included explanations from the teacher and classroom discussions on how and when to apply the skills. In each lesson, attention was paid to one particular step within the empirical cycle. Explicit guidance was included in the form of probing questions and prompts provided during task performance.

Explicit instruction concerning metacognitive skills was addressed by introducing the TASC model throughout the lessons. TASC stands for "Thinking Actively in a Social Context" and aims at giving students structure to support their thinking (Wallace, Bernardelli, Molyneux, & Farrell, 2012). The TASC model consists of a series of questions which can be used to make students aware of the need to monitor and evaluate task execution which is intended to improve metacognitive skill application. In each lesson, students were instructed to think about and discuss the TASC questions with the teacher and with each other.

An instructional framework for explicit instruction of skills was developed by applying two structuring principles. The first involved using the principles of the four-component instructional design (4C/ID) model as a starting point (van Merriënboer, Jelsma, & Paas, 1992; van Merriënboer, Clark, & de Croock, 2002). This involves the implementation of whole learning tasks, together with part-task practice, and includes scaffolding and feedback opportunities. The part-tasks were aimed at strengthening the subskills which were then simultaneously applied to a whole task scientific inquiry. This stimulated the integration of the skills that were practiced separately. A series of lessons structured according to the 4C/ID model involves a careful sequence of part-tasks and whole tasks which gradually increase in difficulty and complexity. The second structuring principle of the instructional framework concerned incorporating the steps of the empirical cycle. For

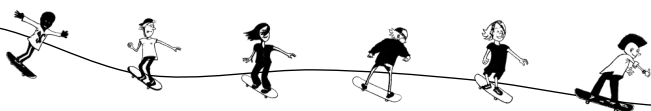
primary science education, a generally accepted guiding principle is structuring investigations by following the main steps of the empirical cycle which include: (1) formulate a research question, (2) formulate a hypothesis, (3) design an experiment, (4) measure and record data (5) analyze results, and (6) formulate a conclusion. The empirical cycle reflects all aspects of a scientific inquiry that are included in most curricula as learning objectives. Most science tasks in primary education are more or less structured accordingly. In the instructional framework, the principle of structuring via the steps of the empirical cycle was applied in two different ways. First, in each lesson, students performed a scientific inquiry (whole task) structured identically into the six steps that represent the empirical cycle. Second, in each lesson, the main focus was on one of the steps only.

In this study, the feasibility and usefulness of the instructional framework including the above described crucial components was demonstrated on the basis of a fully developed lesson. This detailed example lesson illustrated an approach for systematically designing science lessons for primary education according to the principles of the 4C/ID model combined with aspects of explicit instruction.

The implementation of the lessons in a variety of classrooms showed that teachers found the lessons to be feasible to accomplish within their daily practice and the school curriculum for science education. Students found the lessons interesting and stimulating. It was therefore concluded that the instructional framework and the operationalization of science skills into science specific, thinking and metacognitive was not only feasible but provided ample opportunities to construct science lessons which could be aligned with the regular science curriculum in schools.

### **Measuring students' ability to perform a scientific inquiry**

In the third chapter, we explored the construction, the validity and the reliability of different instruments for measuring science skills. The instruments included a paper-and-pencil test, three performance assessments, and two metacognitive self-report tests. Previous research showed that it is generally difficult to attain convergence between tests with different test formats. The problems have been mainly attributed to differences in students' level of content knowledge, inconsistencies in rating and occasion sampling variability (students perform the same task differently on different occasions). To examine whether convergence may be improved as well as to assure that all aspects of scientific inquiry were included, the paper-and-pencil test and the performance assessments were



systematically constructed based on the three subskills (science-specific, thinking, metacognition) as well as on the different steps of the empirical cycle.

The paper-and-pencil test consisted of a total of 46 items that were subdivided into 10 open-ended and 36 multiple choice questions. For administration purposes, the paper-and-pencil test was split into two optimal split-halves. In the performance assessments, students were asked to conduct a small investigation and formulate their findings and answers on a worksheet. All three performance assessments (Skateboard, Bungee Jump and Hot Chocolate) differed in topic but were each constructed according to the same template which consisted of a total of 14 items. One of the metacognitive questionnaires was based on the Junior Metacognitive Awareness Inventory (Jr. MAI) (Sperling, Howard, Miller, & Murphy, 2002) and consisted of 12 items with a three-choice response. The second metacognitive self-report test - Science Meta Test (SMT) - was designed to measure self-regulatory skills and was specifically aimed at obtaining information regarding the application of metacognitive skills in the performance assessments. Because previous research indicated that general cognitive ability is often related to students' ability in performing scientific inquiry (Pine et al., 2006; Roberts & Gott, 2006), the results of a standardized test were collected as well. This test is conducted every year in Dutch primary schools within the context of a student monitoring system and provides an indication of students' general cognitive ability.

The results of the tests which were administered to 128 grades 5 and 6 students showed that the tests were sufficiently reliable. Results also indicated that students' ability to perform scientific inquiry was significantly related to general cognitive ability. Positive correlations between the paper-and-pencil test and the three performance assessments showed that the different test formats measured a common core of similar skills, thus providing evidence for convergent validity. By contrast, we found no relationship between the measure of general metacognitive ability and either the paper-and-pencil test or the three performance assessments. However, the metacognitive self-report test constructed to obtain information about the application of metacognitive abilities in performing scientific inquiry, showed significant - albeit small - correlations with two of the performance assessments.

Additionally, we explored to what extent scores on both subskill and empirical step level can be used to obtain valid and reliable diagnostic information in addition to overall test scores. Each item in both the paper-and-pencil test and the performance assessments was classified by determining the primary skill underlying that particular item. These items were also assigned to one of the steps of the empirical cycle. Then, on subskill and step level, the mean scores, reliabilities and correlations between scores were obtained and

discussed. The results showed that scale reliabilities were acceptable on subskill level for the paper-and-pencil test as well as aggregated across performance assessments. In addition, the correlations between the mean scores of each subskill scale indicated that a more precise identification of students' ability in performing scientific inquiry can be realized.

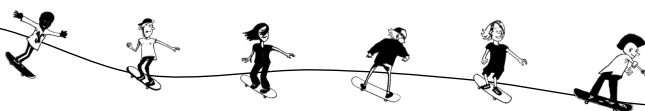
On empirical step level the results showed weak to moderate reliabilities on average and erratic correlations between steps of both the paper-and-pencil test or aggregated across performance assessments. Because of this, we concluded that ability scores on empirical step level should be interpreted with caution, especially when used for summative assessment purposes.

From this study we concluded that with the paper-and-pencil test and the three performance assessments, measurement of science skills can be attained in a reliable and valid manner by systematically constructing items directed to subskills and different empirical steps.

Furthermore, although reliability of skills measured per subskills and step level is limited, we demonstrated that additional diagnostic information for formative purposes can be obtained by examining mean scores on both subskill and step level. By contrast, we concluded that self-report questionnaires were less suitable for measuring metacognitive skills in this group of primary school students and results obtained from these self-report tests need to be interpreted with caution.

## Effects of explicit instruction

The fourth research question that we tried to answer in this thesis concerned the effects of explicit skill instruction on students' acquisition of skills in scientific inquiry. In chapter 4, we described the results of a quasi-experimental study with pretest-posttest design on the effects of explicit versus implicit instruction on the acquisition and transfer of science skills. This study was conducted at 12 schools for primary education in the Netherlands. The participants included a total of 705 students (aged 10-12 years) from 31 grades 5 and 6 classes. The study was designed to investigate the effects of an 8-week intervention with explicit instruction on students' acquisition of inquiry skills (explicit condition). The eight lessons of 90 minutes each of the explicit instruction condition were developed according to the instructional framework described in chapter 2. A control condition was included with lessons in which skills were taught using an inquiry-based approach without explicit instruction on inquiry skills so that information about the added value of explicit instruction



could be obtained. All lessons were piloted in a total of three grade 5 and 6 classes in two different schools before using the lessons for the intervention. To contrast both controlled conditions with regular science lessons at schools, a baseline condition was added in which students followed the regular curriculum. Within schools, classes were randomly assigned to conditions (see for overview Figure 4.2).

To obtain information on the acquisition of science skills, all students were tested with the measurement instruments described in chapter 3. In the pre-test session, the measures included the optimal split-half of the paper-and-pencil test, a performance assessment (Skateboard) and the Jr. MAI self-report test. After the intervention period (8 - 10 weeks), a subsample of the students ( $n = 467$ ) were tested again with the other split-half of the paper-and-pencil test, two performance assessments (Bungee Jump and Hot Chocolate) and both metacognitive self-report tests (Jr. MAI and SMT). Specifically, the topic of the performance assessment Hot Chocolate corresponded with the topic *heat and temperature* addressed in both intervention conditions, while the topic of the performance assessment Bungee Jump was unfamiliar to all students. The last test served to assess the near-transfer of skills to a similar task with a new and unfamiliar topic.

In addition, we included measures to obtain information about the integrity of the implementation of the intervention lessons and whether or not students enjoyed the lessons. The results indicated that there were no significant differences between the two intervention conditions on either of these measures. In both conditions the lessons were taught as intended and in general, students enjoyed the lessons.

Multi-level models with two levels were used to analyze the data of a total of 403 students. The scores on the pre-tests (paper-and-pencil test and the performance assessment Skateboard), general cognitive ability, age, gender and grade level were included as control variables. The scores of the Jr. MAI were not included because of insufficient reliability and lack of variance in post-testing. Results of the analysis of the paper-and-pencil test and the performance assessments showed significant effects for the pre-tests, general cognitive ability and gender. Conversely, grade level did not affect the scores on the post-tests. There was no significant effect of condition on the paper-and-pencil test. However, students of both intervention conditions did significantly better than students in the baseline condition on Hot Chocolate, which was the performance assessment with a familiar topic. Only the explicit instruction condition had a significant positive effect on the ability to apply science skills in a performance assessment (Bungee Jump) with an unfamiliar topic, thus providing evidence for transfer of skills. Students who received explicit instruction not only performed better than did students in the baseline condition, but they also outperformed students of the implicit instruction condition.

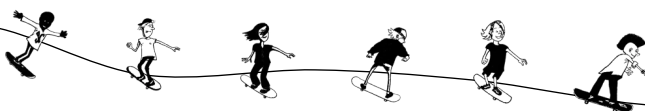
These findings indicated that science lessons can improve skill application in a carefully structured setting with opportunities for students to practice skills in scientific inquiry tasks. The results also showed that systematic and explicit instruction on science skills may be necessary for more robust acquisition of these skills. Increased awareness of metacognitive strategies applied in the tasks by means of probing questions from the TASC model may have further strengthened skills acquisition. However, we did not find improvement for the paper-and-pencil test and the SMT and as such did not match the outcomes of performance measured by the performance assessments. For the paper-and-pencil test, this lack of progress may be attributed to the test format: the paper-and-pencil test consisted of primarily multiple choice items. Accordingly, the paper-and-pencil test was less similar to a real-life inquiry than it was to the performance assessments, and the tasks that were carried out in the lessons. For instance, formulating a research question for a “real” inquiry is not the same as identifying a research question from amongst different multiple-choice options.

The SMT failed to elicit development of metacognitive skills, which may be due to limited sensitivity of the test. An alternative plausible explanation could be that students overestimated their metacognitive skills. It is therefore conceivable that many students in grades 5 and 6 did not yet have a mastery of these skills even though they thought that they did.

## **Performance assessment as a diagnostic tool**

In the final study we discussed the research question which focused on whether performance assessments have added value as a diagnostic tool to guide instruction in science classroom practice. In chapter 5, we explored and discussed the use of performance assessments for formative assessment to inform teachers and guide instruction of science skills in primary education.

In general, in daily classroom practice, teachers will spend more time and effort on summative assessments rather than on formatively assessing their students’ progress. However, the information on students’ development of science skills is essential for teachers in order to evaluate and improve upon their own instruction, as well as to provide adequate support and feedback on the learning process of individual students. When developing performance assessments, the structure of these assessments should also provide opportunities for formative evaluation in the classroom. This way, a more fine-grained picture of students’ acquired skills may be obtained and used by the teacher to



guide students' learning. In this study, we explored and discussed the utility of the more specific information that may be obtained by structuring the performance assessments according to the different steps of the empirical cycle.

To this end, we examined the mean scores of the 403 students who had participated in all three performance assessments (Skateboard, Bungee Jump and Hot Chocolate) on "step level". In addition, we analyzed the response patterns and illustrated these patterns with examples of students' responses.

In general, mean scores showed that the performance assessments were difficult for most 5 and 6 grade students. However, the difficulty seemed to depend on the step-level of the empirical cycle. For instance, designing an experiment appeared in general to be more difficult than formulating a hypothesis. Differences were also visible between performance assessments. For example, in Bungee Jump and Hot Chocolate the mean scores for "measure and record" were higher than those in Skateboard. The response patterns revealed that much individual variation existed regarding the different steps of the empirical cycle. That is, scores were spread within almost each step, although most students scored in the lower regions of the points awarded. In particular for the steps of designing an experiment, analyzing results and formulating a conclusion, most students attained low scores. In addition, the examples of student responses provided insight into typical errors that students made. For instance, students' experiment designs were in general not specific and missed the relevant detailed information needed to understand exactly how the experiment should be executed. Common errors found in the step of analyzing results involved neglecting to base the conclusion on the actual data collected by the students.

Based on these findings, we argued that the approach of implementing performance assessments and analyzing students' responses can be used by teachers to obtain information on how students perform as a group at the classroom level. This approach also reveals the steps with which students have particular difficulty. Because of this, teachers can use this information to adjust their instruction and activities in the classroom. Students' responses may enable teachers to provide individual students with specific feedback. We were able to conclude that performance assessments may be useful as a diagnostic tool for monitoring students' skill performance as well as to support teachers in evaluating and improving their science lessons.

## 6.2 Discussion

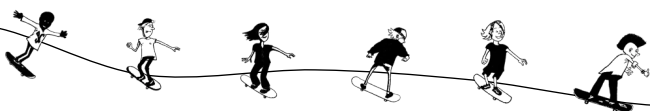
### Theoretical contribution

This thesis contributes to previous research by showing that categorizing science skills into three different types (science specific, general thinking and metacognitive) adds to a more structured approach when designing science lessons as well as when designing assessment instruments. Although the idea that the general concept of science skills is related to various cognitive abilities has been acknowledged in previous research (e.g., Duschl, Schweingruber, & Shouse, 2007), limited attention has been paid to the application of these concepts of underlying skills to the design of science lessons. In this research project, we not only operationalized science skills into three types of skills, but we went a step further and systematically applied the categorization of skills in order to design an instructional framework aimed at the acquisition of these different skills. We also applied the categories of science-specific, thinking and metacognition to the design of measurement instruments. As a result, we ensured the alignment of instruction and evaluation and contributed to a reliable assessment of science skills.

### Instruction of science skills

The results in the first place confirmed previous research by showing that teaching methods with explicit instruction support the acquisition of science skills and can therefore improve students' ability to perform an investigation (Klahr & Nigam, 2004; Lazonder & Harmsen, 2016). In this research project, explicit instruction was not limited to direct instruction, which is often perceived as primarily teacher-centered where the teacher explains how things should be done. Instead, we included a range of different aspects to shape explicit instruction based on theories and previous research on, for example, the effectiveness of feedback and the use of prompts and probing questions (McNeill, Lizotte, Krajcik, & Marx, 2006; Sahin & Kulm, 2008; White & Frederiksen, 2000).

One important aspect of explicit instruction concerned the teaching of the metacognitive skills. Previous research established that metacognitive skills such as monitoring and evaluating one's own performance, may enhance the quality of task performance (Schraw et al., 2006). For this reason, we used the TASC model to support the development of students' metacognitive skills (Wallace et al., 2012). The TASC model





includes probing questions which we used to explicitly direct students to apply a certain strategy to the process of the scientific inquiry. This explicit instruction by using the TASC model was implemented in the following ways: first, by the teacher explaining how to use the probing questions; second, by including the TASC questions in the student material to encourage the students to apply the strategies at certain crucial phases of the inquiry process; and third, by supplying the students with a booklet which they could access and use at any time during the lessons.

The second main aspect of explicit instruction included attention to the way in which teaching and learning scientific inquiry could be structured. For this research project, we structured all inquiry tasks using the steps of the empirical cycle. The sequence of steps of the empirical cycle provided a structure that was recognizable for students and helped them to understand how the inquiry process can be organized. This is particularly important for students in primary education who have little experience with inquiry tasks (Donovan, Bransford, & Pellegrino, 1999; White & Frederiksen, 2000). This structure was made clear to the students by including visible illustrations in the classroom (in the form of a poster) and in the student material. In each subsequent lesson, one of the steps was explicitly taught and practiced.

We found that the application of explicit teaching methods aimed at science skills development led to more effective development of students' ability to perform a scientific investigation, hence adding to the discussion of the role of explicit versus implicit instruction regarding the skills in performing a scientific inquiry in science education.

Another contribution of this research project is that we showed how to integrate these features of explicit instruction into an instructional framework with skill acquisition as its focus. The instructional framework was structured based on the steps of the empirical cycle as well as on the categorization into the three types of skills. As discussed above, the principle of structuring by means of the steps of the empirical cycle was twofold: 1) to ensure a consistent structure of each inquiry task and 2) to direct the sequence of the intervention lessons. The categorization into underlying skills led to systematically incorporating activities aimed at developing each of the skills. For instance, each lesson consistently included an evaluation of the skills that were taught and practiced, thereby stimulating students' metacognitive skills.

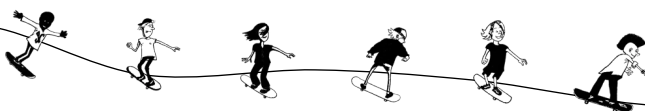
We further showed that the theoretical model of the four-component instructional design (4C/ID) of Van Merriënboer, Jelsma, and Paas (1992) contributed to systematically addressing skills in the various stages within science lessons and in particular to the integrated use of the skills. To our knowledge, the 4C/ID model had never before been applied to developing science skills for primary education. In this research project, we

applied the model to our instructional framework because of its usefulness for designing lessons aimed at skill acquisition. In particular, an important asset was the opportunity to incorporate small part-tasks for practicing skills and then to apply all skills simultaneously in more complex scientific investigations, thus stimulating integration of the skills. Moreover, the 4C/ID model offered the possibility to design lessons for both the explicit and implicit instruction condition. In this thesis, we have shown that the lessons based on our instructional framework led to positive outcomes and as such may add to the body of knowledge about skill development of primary school students.

It should be noted however, that although positive effects of explicit instruction were established on students' overall ability to perform a scientific inquiry, positive effects were not found on their metacognitive skills as measured by the self-report questionnaires. A first possible explanation for this result could be that our intervention which comprised a total of eight 90-minutes lessons was not long enough to cause metacognitive skills to become more deeply engrained. Considering the complexity and amount of skills these inexperienced students had to acquire, the metacognitive skills may have received too little attention in the lessons. This is in line with previous research showing that developing metacognitive skills takes time and effort to fully develop (see also Mahdavi, 2014; Veenman, van Hout-Wolters, & Afflerbach, 2006). Secondly, it is possible that our assessment instruments were not adequate and sufficiently fine-grained to reliably measure the underlying skills separately.

Another conclusion that can be drawn from this research project is that the implicit teaching method also supports skills acquisition when performing a scientific inquiry, albeit to a lesser extent than that of explicit instruction. The lessons of the implicit condition lacked all aspects of what constitutes explicit instruction such as direct instruction of the teacher, the use of prompts and probing questions, and explicit attention to the steps of the empirical cycle. However, this does not mean that students had to find out everything for themselves. Instead, the lessons were also carefully organized and included scientific experiments that were structured in accordance with the different steps of the empirical cycle. In addition, the science experiments increased in difficulty level and complexity throughout the course of the eight lessons. Hence, our finding suggests that in a carefully structured setting, the opportunity to practice skills alone can already improve skill application. This is in line with results of previous research indicating that learning by doing can promote the development of skills, such as of the Control of Variables Strategy (CVS) (Dean & Kuhn, 2007).

Interestingly, we did find evidence suggesting that only explicit instruction may facilitate transfer of science skills. One of the two post-test performance assessments



implemented to measure science skills, namely the performance assessment Bungee Jump, was designed specifically to measure (near) transfer of skills. That is, the topic of Bungee Jump was different from the main topic of heat and temperature that was dealt with during the lessons. The results showed that the students who had received explicit instruction outperformed the students who had merely acquired the skills though the learning-by-doing method. The conclusion that can be drawn from this finding is that explicit instruction as it was shaped in our instructional framework may have promoted more robust comprehension of the acquired skills. Although this result confirms findings of previous research in CVS studies (Klahr & Li, 2005; Kuhn et al., 1995), we now established that this may be the case for a broader array of skills.

Overall, an important contribution of this research project is that we learned how to design effective explicit instruction at the primary school level and that the outcome is not primarily declarative knowledge - which is common in science classrooms - but also procedural knowledge as represented in the performance assessments. The implication here may be that not only can students learn to apply skills when hypothesizing, devising an investigation or manipulating equipment, but they may also be able to concurrently develop an understanding of the value of the procedures and activities involved in scientific inquiry (Gott & Duggan, 1996).

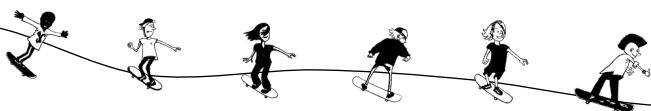
Finally, applying our theoretical instructional framework to design lessons which were taught in a real-life classroom setting added to the significance of our results. We were able to show that the positive effects of explicit instruction can also be established within a classroom setting. Moreover, we have shown that the lessons based on this model can be implemented in many different schools and by many different teaching assistants, thus realizing high ecological validity.

### **Assessment of science skills**

In contrast to previous studies (e.g., Pine et al., 2006), we attained somewhat greater alignment between different test formats (paper-and-pencil test and performance assessments) and between the three different performance assessments. Alignment was realized in various ways. First, items were included that represented the various underlying skills. As a result, all tests provoked similar cognitive demands. This means that not only were practical aspects such as recording measurements included but also those aspects which demand higher order thinking such as analyzing results. Second, the steps of the empirical cycle were used as a general blueprint for test construction. By doing this, all tests comprised items for measuring students' ability to, for example, formulate a research

question. Third, each performance assessment was constructed according to the same template. All items were identical and differed only when referring to the specific topic of the performance assessment. Nevertheless, as was also reported in previous research, we still found considerable differences between scores of the tests intended to measure the same skills (Baxter & Shavelson, 1994; Pine et al., 2006). In addition, the correlations between tests and scores on general cognitive ability showed that general cognitive ability influenced the test scores. This was especially the case for students in the baseline condition, who did not receive lessons specifically aimed at the acquisition of science skills. In addition, pre-tests showed more shared variance with general cognitive ability than did the post-test performance assessments. These findings are in line with previous research in which general cognitive ability was found to have a major impact when skills were measured, especially in novice learners (e.g., Roberts & Gott, 2006). As argued by Pine et al. (2006), without powerful instruction, students are forced to rely on their general abilities and prior knowledge in order to accomplish a task. It may be concluded that, although the problems concerning convergence between different test formats still existed within our research project, the findings in this thesis add to the ongoing discussion of assessment of science skills. Especially given that assessment seems to be a limited innovation in science pedagogy (cf. Davey et al., 2015; Pellegrino, 2012), it is important to explore and discuss the issues and problems regarding these kinds of assessments.

In this research project, we constructed the assessment instruments based on the premise of the categorization of science skills into three underlying types of skills. Although our results to some extent indicated that the underlying skills are indeed different abilities, our instruments did not discriminate sharply between the three types of skills. In the first place, it may be that although we assigned each item in the tests to one of the three underlying skills, these items did not exclusively assess each particular type of skill. Indeed, items were assigned to one of each underlying skill which was primarily expected to influence actual performance on this particular item. For instance, we assigned items on designing and conducting an experiment to the category of science-specific skills. However, metacognitive skills may also have influenced performance on this particular aspect of the test. Therefore, the items in the tests may have measured the integrated application of the skills and are as such not suitable for assessing one clear demarcated subskill. A second explanation for this result could be that although we made the division into three types of skills, these skills may not actually be sharply distinct concepts. Moreover, the categorization into three underlying skills is still rather general. For instance, thinking skills can be further classified into problem-solving, reasoning, decision-making, inductive and deductive thinking, creative thinking (Adey & Serret, 2010; Gubbins, 1985;



Sternberg, 1986). However, designing tests with such detail may more adequately test skills but may at the same time be less valid and useful in assessing actual performance of a scientific inquiry in which skills are applied in an integrated way.

It can thus be concluded that although operationalization of science skills into the three categories of skills remains somewhat opaque when trying to identify these categories within the assessments, using the proposition of the categorization into three underlying skills to structure assessments did contribute crucially to improved alignment between tests, as well as provided the opportunity to ensure the incorporation of the various cognitive demands of a scientific inquiry. We may also conclude that the intervention succeeded to some extent in teaching students to integrate the skills when applying them to a scientific inquiry.

The final contribution of this thesis is that we add some important findings to the current discussion on assessing metacognitive skills in science education. In this research project, we administered a variety of assessments instruments in an attempt to assess the acquisition of metacognitive skills. First, we included items in the performance assessments which were directed to assessing metacognitive skills such as monitoring and evaluating task performance. We also administered two different self-report questionnaires: Jr. MAI (Sperling et al., 2002) and the SMT. The Jr. MAI questionnaire was used to measure metacognitive skills in general in contrast to the SMT which was aimed at measuring metacognitive skills which were applied in the context of the performance assessments. Results revealed that progress could not be measured by means of the Jr. MAI and only somewhat better by means of the SMT. In particular the Jr. MAI showed insufficient reliability and both the Jr. MAI and the SMT showed very low variance. From this, we may conclude that self-report questionnaires may not be the proper way to assess young students' metacognitive skills which is consistent with previous research (see for discussion Veenman, van Hout-Wolters, & Afflerbach, 2006). The young and inexperienced students participating in this research project may have, in particular, appraised their own metacognitive skills too positively. Another argument that affirms the statement about using self-report questionnaires is that it is possible that the metacognitive skills did improve and - although not directly measured by the Jr. MAI or the SMT - are indirectly reflected in higher scores on the performance assessments (Georghiades, 2000). This is in line with previous studies showing that metacognitive skills have a positive influence on performing a scientific inquiry (White & Frederiksen, 1998).

Also a conclusion of this research project is that, in the case of assessing young students, it may be essential to measure metacognitive skills in a task-specific context. The SMT which was constructed to obtain specific information about the application of

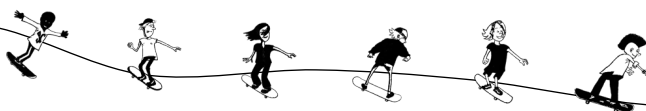
metacognitive skills in performing science tasks, showed significant - albeit small - correlations with the two performance assessments that were administered after the intervention period. In contrast, the Jr. MAI which is a general measure of metacognition, did not relate to any of the performance assessments. This may indicate that, when performing a scientific inquiry, it is preferable to assess metacognition with items that are related to metacognitive activities where students have a clear understanding of both science context and task. In other words, students may be more capable to estimate their metacognitive skills when they can relate it to a specific task they performed (Schellings, van Hout-Wolters, Veenman, & Meijer, 2013). Because of this, we would suggest the implementation of more task-specific instruments to measure metacognitive skills for primary school students.

### **Limitations and suggestions for future research**

The present thesis has generated two important results. First, an effective approach for teaching science skills and second, a variety of measures to assess science skills in order to determine the levels of students' ability, which were also useful for diagnosing student problems and informing instruction (formative assessment). The research project had a quasi-experimental design with a large sample to gain sound evidence regarding empirical standards of research and high ecological validity at the same time. In total, a great amount of attention was spent in ensuring objectivity and validity. However, we attach importance to discuss some critical reflections that can be made concerning the scope of our research and to suggest some recommendations for future research.

The first limitation to this research project is that we cannot be sure whether all primary school teachers are able to teach the lessons as intended. We trained research assistants who had been recruited and trained specifically for the purpose of teaching the intervention lessons. All assistants had either graduated or were in the final year of an elementary teacher education program. This way, we were able to control the way the lessons were taught, hence improving objectivity and thus reliability of the results. However, to see the extent to which the same results would be attained, we would recommend having the lessons taught by the students' regular primary school teachers.

The second limitation in this thesis concerns the use of self-report questionnaires for measuring metacognitive skills. Using self-report tests has the major advantage that they are easy to administer and score for large scale testing such as in this research project with a large sample. A disadvantage was that the young students participating in this



research project were not used to filling out self-report tests. They may have lacked the ability to reliably assess their own abilities. A mix of various methods, such as observations, teacher ratings, or think-aloud methods may have rendered more insight into students' metacognitive skills. However, these methods also have limitations, in particular for large scale use (see for discussion Vandevelde, Van Keer, & Rosseel, 2013). For future research, we would recommend using other methods along with self-report tests to attain more valid and reliable measurement of metacognitive skills.

A third limitation regarding the effect study concerns the duration of the intervention. In this study, the number of lessons was limited to eight. It is generally acknowledged that skills - and in particular skills in the higher order thinking category - develop slowly (e.g., Lehrer & Schauble, 2006). Commonly, science curricula allocate several years for the acquisition of science skills. It would be interesting to see how the students would perform had they been given more time to develop science skills. Moreover, the research assistants who taught the lessons did so for the first time. We suggest that future research should consider implementing lessons for a longer period of time and have the lessons be taught by experienced teachers who are already familiar with several iterations of these particular lessons.

A final limitation is that we did not include more open inquiry tasks. In this research project, we used performance assessments to assess actual real-life performance. These particular performance assessments were still highly structured and constrained. For instance, students did not have the opportunity to investigate a research question of their own choice. Therefore, it may be argued that we did not test the full range of students' possibilities. For future research, it would be interesting to explore how students would apply their skills to less structured assessment formats.

## **Educational implications**

This thesis presents an extensive analysis of the measurement issues and instructional methods needed in order to foster development of science skills. We think that this thesis may help to inform educators, teachers and other stakeholders when they design and teach lessons aimed at the acquisition of science skills.

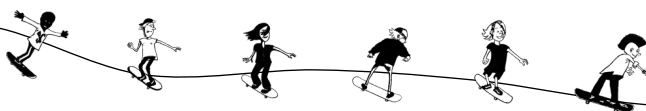
First, it is important that teachers are aware that learning science skills is not only a matter of incorporating hands-on experiments as just a "fun" part of science lessons. Instead, learning science skills is as difficult and needs as much attention as acquiring science content knowledge. We argue that students need carefully structured instruction in

which all cognitive aspects regarding a scientific inquiry are purposefully addressed. For example, we suggest that teachers design and use educational material which provides students with the opportunity to learn and practice skills separately in smaller part-tasks, in addition to more complex scientific investigations in which the students apply all skills simultaneously. These whole-task investigations should also be part of a learning trajectory from simple to more complex depending of the level of students' ability to apply science skills. Furthermore, students need support when performing a scientific inquiry. We would advise teachers to use more feedback and prompts, and promote students' metacognitive skills such as monitoring and evaluating, by implementing explicit questions to help students develop these skills.

Second, we would recommend not limiting measurement instruments to paper-and-pencil tests but to include performance assessments as well. The benefits are plentiful: for instance, by using more than one testing format, a more valid and fine-grained picture of students' abilities may be obtained. In addition, the specific structure of the performance assessments can be used formatively so that teachers are able to design and adjust their instruction in response to the students' (lack of) progression. Moreover, the experience of having administered performance assessments not only makes teachers more attentive during regular class activities, but also makes them better able to identify learning and to remedy problems with respect to science skills.

Third, the design of the instructional framework in which science skills are categorized into three categories can be used by primary science curriculum designers and educators to integrate science lessons with other subjects such as language and mathematics (van Graft, Klein Tank, & Beker, 2014; NRC, 2012). Not only will this ensure a more solid position of science in curricula of primary education but also students could benefit from the wider selection of occasions in which they can apply the general thinking and metacognitive skills. We think that the diversity of tasks for which the skills are used will eventually help foster a deeper understanding and ultimately a more wide-ranging transfer of these skills throughout the primary school curriculum.

Finally, we illustrated how the theoretical ideas of the 4C/ID model and the TASC model could be incorporated into an instructional framework and then be used to design science lessons. The added value is that these lessons were taught in actual primary science classrooms which offered ecological validity. Furthermore, as an illustration of the applicability and relevance of the lessons for primary schools, we would like to point out that upon completion of the research project, one of the participating primary schools located in Amsterdam built the explicit teaching method into their regular science curriculum. This school is currently training their teachers to apply this method to other





grades besides just grades 5 and 6. Additionally, some grade 6 students at this school are mobilized to assist students in lower grades in performing scientific inquiries within the lessons. This example demonstrates that the research project provides a powerful argument for the use of the instructional framework when designing not only effective, but also relevant lessons for learning science skills in primary education.



# APPENDICES

- APPENDIX A. Experiment in lesson 1
- APPENDIX B. Example items of paper-and-pencil test
- APPENDIX C. Example of scoring model for making a graph
- APPENDIX D. Example of scoring rubric of formulating a research question in performance assessment Skateboard
- APPENDIX E. Examples of tasks of the explicit condition and the implicit condition
- APPENDIX F. Example of a performance assessment: Skateboard

# APPENDIX A

## Experiment in lesson 1

### Experiment 1 Warm or cold?

Now that you have learned how to formulate a research question, you are going to apply this in the following experiment. You work together on the experiment.

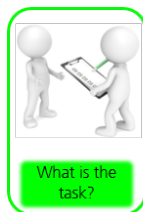
I am working with: .....

Do you feel it is warm or cold outside? It is difficult to tell just by feeling. It also depends on whether you have been running or calmly playing with your marbles. Ask others and you will see that everybody has a different opinion.

If you jump into the pool, the water feels cold. If you take a shower afterwards, the water will feel nice and warm. But how could you know for sure how cold or how warm the water actually is? The purpose of this experiment is to find this out.

#### What do you need?

- ✓ A beaker with very cold water
- ✓ A beaker with lukewarm water
- ✓ A beaker with warm water
- ✓ Two thermometers
- ✓ Stopwatch



Answer the following questions. You do not need to write them down, but talk about the answers in your group.

What is the goal of the task?  
What do I need to complete the task?  
Do I need more information?

#### What are you going to do?

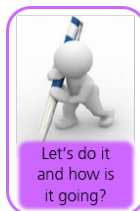
- 1) Put two fingers of your left hand in the beaker with warm water and two fingers of your right hand in the beaker with very cold water at the same time.
- 2) Your classmate sets the stopwatch on 90 seconds.
- 3) After 90 seconds, you put all four fingers at the same time in the beaker with lukewarm water.
- 4) Write down what you felt with the fingers coming from the cold water and what you felt with the fingers coming from the warm water.
- 5) Now put a thermometer in the beaker with cold water and a thermometer in the beaker with warm water. Write down the temperature.
- 6) Now leave the thermometers for 90 second in the water. After the 90 seconds, put both thermometers at the same time in the beaker with lukewarm water. Write down the temperature on both thermometers.

Formulate a **research question** for this experiment. Use the *Question Machine*.

Our research question is:

.....

Now you can do the experiment.  
Go and get the materials you need  
and follow the instructions.



Answer the following questions. You do not need to write them down, but talk about the answers in your group.

How do I check my progress?  
Am I doing it correctly?

Write down the results:

1. What did you feel when you put your fingers in the lukewarm water after the warm water?

.....

2. What did you feel when you put your fingers in the lukewarm water after the cold water?

.....

3. What did the thermometer read in the warm water? .....° C

4. What did the thermometer read in the cold water? .....° C

5. What did the thermometer read in the lukewarm water coming from the warm water? .....° C

6. What did the thermometer read in the lukewarm water coming from the cold water? .....° C

7. What is the best way to measure the temperature of water, do you think? Explain your answer.

.....






8. Did you get an answer to your **research question**? If so, what is the answer?

.....

APPENDIX B

Example items of paper-and-pencil test

Mustafa puts four leaves in a container together with a caterpillar. He checks the leaves every day. What can he tell from what is happening with the leaves every day?

Monday	Tuesday	Wednesday	Thursday	Friday
				

A. The caterpillar only eats every other day.  
B. The caterpillar eats every single day.  
C. The caterpillar will eat a piece of a leave the next Monday.  
D. The caterpillar will stop eating on Friday when he is going to pupate.

Figure B.1  
*Item in which students make inferences informed by evidence and reason, assigned to thinking (SOLpass.org).*

In the figure you can see a thermometer. The thermometer is hanging in a room. What is the temperature in this room?

A. 19° C  
B. 20° C  
C. 21° C  
D. 22° C

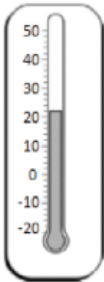
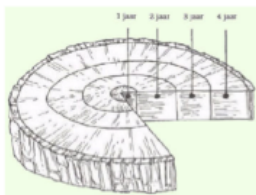
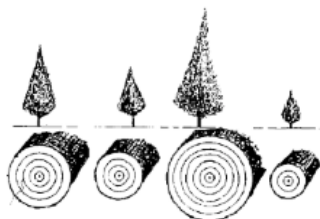


Figure B.2  
*Example item assigned to science-specific: observe/measure correctly (Fraser, 1979).*

When we cut across the trunk of a tree we see growth rings:



The trees below were planted at different times in the same wood. The drawings underneath show the growth rings seen when the trees were cut down.



What pattern do you see linking the heights of the trees and the rings in the trunk?

Write your answer below:

.....

Figure B.3

*Open-ended item in which students identify patterns, assigned to thinking (Harlen, 1986).*

A group of children wanted to find out how fast a plant grows. For 6 days in a row the children kept a record of how much the plant grew. They saw that the plant grew 1,5 cm on each day. The children put the results in a table. What does the table look like? Make a table and note the results.

Figure B.4

*Example open-ended item in which students record data, assigned to science-specific.*

# APPENDIX C

## Example of scoring model for making a graph

For both labeling the axes and drawing the line, points are awarded and subsequently added. Fill out this score.

0	No numbers at axes / numbers count backwards on one of both axes	
1	<div>-numbers are (linearly) and evenly spread on axes -numbers start with 0* (if not mentioned, but space is made) -large part of space used (more than half the space available)</div>	} 2 out of 3 points
2	Numbers are (linearly) and evenly spread on axes; large part of space used (more than half the space available); numbers start with 0* (if not mentioned, but space is made); all measurements fall into space available.	

0	A bar chart is made / there are no data points	
1	A line is drawn, but the data points are not correct / data points are correct, but no line is drawn.	
2	All data points are correct; a line is drawn through the data points / there is a line of best-fit.	

Goal:  
The student is capable of drawing a graph. The numbers of the axes are correct (starting with zero of space left open in first cell) and the data points are noted correctly. A line has been drawn through the data points. The graph uses most of the space available.

Notes:

- No points are deducted when helping lines are drawn.
- If a random line is drawn without taking into account the data points: no points are awarded for line.
- If numbers are not on the lines of axes, but instead between lines, no points are deducted.

\* numbering must be sequential between zero and the next number. For instance: (-)-5-10-15 or (-)-2-4-6. And not: (-)-50-55-60, unless specifically a cell is left open.



## APPENDIX D

### Example of scoring rubric of formulating a research question in performance assessment Skateboard

Item 1 Research question

Can you think of a research question you want to find an answer to?

Write down your question:

0	Leaves space empty / formulates a question not relevant, understandable or possible to investigate / just refers to illustration.	<i>Who is right?</i> <i>Who rolls further?</i> <i>How can they go faster?</i>	<p>Goal:</p> <p>The student is able to formulate a research question relating to the goal of the investigation. Goal of the investigation is to find the relation between the distance on the ruler and the distance the marble covers at the end of the ruler. The research question is relevant if it leads to finding this relation.</p> <p>Notes:</p> <p>If a relation is mentioned, but speed is included, only 1 point is assigned. In case formulation leads to answering yes/no: no points are subtracted.</p>
1	Formulates a researchable question which can be answered with results of this experiment, but has no connection to relationship between distance on ruler and distance marble rolling. (Question is on itself understandable and relates to the context of skating (or marbles)	<i>Can the marble roll a distance of 15 cm?</i> <i>How far can the marble push the paper wedge?</i> <i>Do you go faster when you start higher up the hill?</i>	
2	Formulates a researchable question which can be answered with results of this experiment and (explicitly) identifies the relationship between distance on ruler and distance of marble rolling.	<i>Does the marble roll further when the marble starts higher up the hill then when the marble starts at a lower point?</i> <i>Do you go further when you start higher up the hill?</i>	

## APPENDIX E

### Examples of tasks of the explicit condition and the implicit condition

#### Tasks in the **explicit** condition:

In the previous two lessons you learned how to formulate a research question and a hypothesis. In order to find an answer to a research question, you can do an experiment. You then need to think about how you are going to perform the experiment. In other words: make a design. In this lesson you are going to design an experiment. You make a plan for how to do the experiment.

A design helps you to carry out the experiment. With a design, you can avoid skipping important steps which may lead to your experiment failing. Also, when your results are different from what you expected, it enables you to look back and see what you might do differently next time. Another advantage is that you can do the same experiment a year later again without having to rethink what you have done.

What does a good design involve? You should write out the design so that other researchers would be able to do the experiment in exactly the same way. A good design includes:

- ✓ The materials you are going to use
- ✓ How many of the materials you need
- ✓ What the materials look like
- ✓ How to use the materials
- ✓ How you are going to measure
- ✓ How often you will take measurements
- ✓ How long you will measure
- ✓ What you keep the same while measuring and what you will change
- ✓ How you divide tasks in your group
- ✓ An empty table for your results

The table is an important aspect of your design because it includes various points in the design. Take a look at the following example:

Height from which you drop the ball	Height the ball reaches when bouncing back
1.00 meter	
1.25 meter	
1.50 meter	
1.75 meter	
2.00 meter	

What you change.


What you measure.

These are 5 measurements. That is a reasonable number to show how the drop height relates to the bounce height.

You put your results here while measuring.

### Experiment: Tea

Now that you know how to make a design, you are going to make a design for the following experiment. The goal of the experiment is to find out how quickly water cools in different containers. An investigation always starts with a research question and a hypothesis. First think about the following questions:



What do I know about this?

Answer the following questions. You do not need to write them down, but talk about the answers in your group.

What information do I have?  
Do I understand what I should do?  
Have I done this before?  
What are the questions I can ask?

You work together on the experiment.

I am working with: .....

Now formulate a **research question**. Use the *Question Machine!*

Our research question is:

.....

Our **hypothesis** is:

I think that....., because....

.....

Make a **design** and use the list.

**You have ten minutes to do the measurements.**

Our design is:

.....

.....

.....

.....

.....

A good plan contains:

- ✓ The materials you are going to use
- ✓ How many of the materials you need
- ✓ What the materials look like
- ✓ How to use the materials
- ✓ How you are going to measure
- ✓ How often you will take measurements
- ✓ How long you will measure
- ✓ What you keep the same while measuring and what you will change
- ✓ How you divide tasks in your group
- ✓ An empty table for your results

Tasks in the **implicit** condition:

1. In the previous lessons you learned about conduction and heat transfer. You have now watched a film about ducks with cold feet. We discussed the film together. Write down what you have learned from watching the film.

.....

.....

.....

2. Also, the teacher explained that fluids and air are poor heat conductors. But heat can flow to its surroundings by convection through water or air. This is a different kind of heat transfer where moving hot water or hot air transports the heat. What are heat sources in your home and at school? Make a list. Measure or make an estimate of the temperature of each heat source and write it down in the table below.

Heat source	Temperature
1. radiator	70° C
2.	....° C
3.	....° C
4.	....° C
5.	....° C

3. How does heat transfer in the following examples? After each sentence, write down 'conduction' or 'convection'.

The stone floor feels cold with bare feet.	
You burn yourself on a hot pan.	
Your warm bath is getting colder.	
A baby has a hot water bottle to keep it warm.	

4. Hot tea is an example of a heat source. Because the heat of the tea flows to the colder air, the tea will get cold. The colder the surrounding air is, the faster the tea will cool down. There are also other aspects which influence how fast hot tea cools down. Can you think of other ways to cool tea even faster?

.....

.....

.....

#### Experiment: Tea

When you have a cup of tea you will notice the tea cools down after a while. The tea you spill on the saucer cools down even faster than the tea in the cup. What could be the reason? How would you investigate this? And how would you investigate whether or not the spilled tea really does cool faster than in a cup?

You work together in this experiment.

I am working with: .....

What do you need?

- ✓ cup
- ✓ bowl
- ✓ hot water
- ✓ two thermometers
- ✓ stopwatch
- ✓ beaker
- ✓ ruler



1. Formulate a research question for the experiment:

.....

2. What do you think the answer will be? Write down your answer and the reason why you think that. My hypothesis is:

I think that....., because....

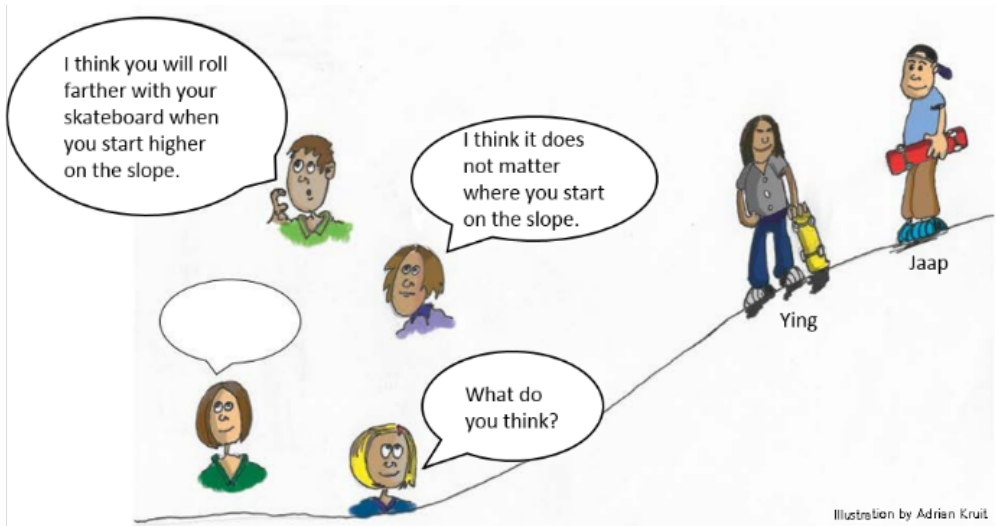
.....

3. Make a design for your experiment. Describe exactly what you will do. Also write down how you will measure, how often you will measure and how you will record your measurements (in the table).

.....  
.....  
.....

## APPENDIX F

### Example of a performance assessment: Skateboard



Jaap and Ying want to roll down the hill with their skateboards. Each boy starts at a different height. Jaap thinks that he will roll farther than Ying at the bottom of the hill. Ying thinks that he will go farther than Jaap. You are going to investigate this. It is not possible to skateboard in the classroom, so the experiment will be performed on your school desk. First, you will be required to complete the following assignments:

#### Task 1:

Can you formulate a question pertaining to your experiment for which you would like to find the answer? Write down your question.\*

#### Task 2:

You will carry out an experiment in which you will try to find an answer to the following question:

*Will you roll farther when you start higher up on the slope?*

There are materials on the table. You will let the marble (= skateboard) roll from the ruler (= slope). On another table, you will see an example of the set-up you are going to use. Build the set-up with your own materials.

Now you are going to make a design for your experiment. Describe in steps how you will perform your experiment. For example, think about what you will measure, how and how often you will measure it. Also, describe how you will record the results of your experiment.

**Task 3:**

What do you think the answer will be for the research question: Will you roll farther when you start higher up on the slope?

I think that....., because....  
.....

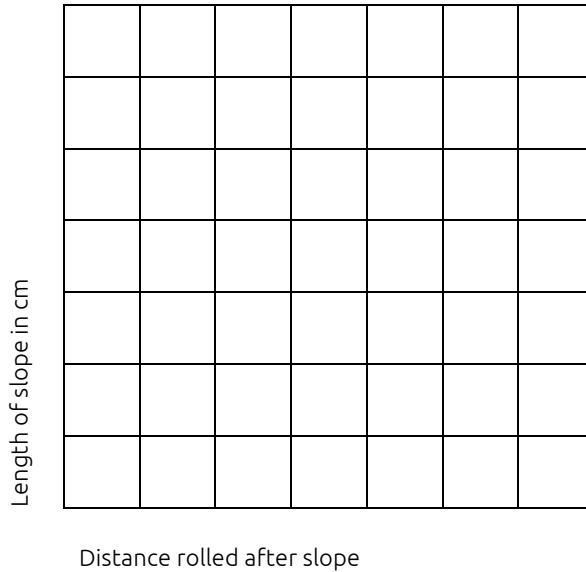
**Task 4:**

You will execute your experiment following your own design in Task 2. The purpose is to find an answer to the research question: Will you roll farther when you start higher up on the slope?

a) Record the results in the space below. Think about how you will write down the results.



b) Make a line graph of your results:



**Task 5:**

You can answer the following questions by looking at your results and your graph.

- a) Describe how the distance the marble rolls on the slope relates to how far the marble continues to roll beyond the slope.
- b) Suppose that you could make a slope that is 2 meters long. How far would the marble be able to roll beyond the slope? Explain your answer.

**Task 6:**

- a) Reread the research question for task 2. What will your answer be now?
- b) Which reasons can you give to show that your answer is correct?

### Task 7:

- a) In Task 3 you described the results you expected. Now that you have done the experiment, which similarity and/or difference is there between what you expected and what you found in the investigation? Explain your answer.

In Task 4 you designed your experiment. The following three questions are about the execution of your investigation.

- b) What - if anything - did you end up doing differently than was described in your design?
- c) If you did anything differently, what was your reason for doing so?
- d) If you carried out your design according to your plan, what would you do differently next time round in order to improve upon your experiment? Explain your answer.
- e) Perhaps your curiosity was piqued after having performed this experiment. Suppose that you could use different (or more) materials and had more time. What would you investigate or change about your experiment regarding skateboarding?
- f) You investigated the distance travelled on the slope and the distance the marble continued to roll beyond the slope. What can you now say about the rolling of Jaap and Ying's skateboards?
- g) What did you learn about doing an experiment?

\* In the actual assessment, each question was followed by dotted lines for students to write their responses on.





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# CHAPTERS IN THIS THESIS AND CONTRIBUTIONS OF CO-AUTHORS

## **Chapter 2 is based on:**

Kruit, P. M., Oostdam, R. J., van den Berg, E., & Schuitema, J. A. (submitted). An instructional framework for teaching science skills in primary science education.

## **Contributions:**

Patricia Kruit is the first author of this article. She reviewed literature, collected and analyzed the data, and drafted the various versions of the paper. The research team further consisted of Ron Oostdam, Ed van den Berg and Jaap Schuitema, who were the supervisors of Patricia Kruit. This research team collaboratively conceptualized and designed the study. In addition, the research team discussed all the steps in the process of the design and outcomes. The supervisors reviewed the manuscript and provided feedback.

## **Chapter 3 is published as:**

Kruit, P. M., Oostdam, R. J., van den Berg, E., & Schuitema, J. A. (2018). Assessing students' ability in performing scientific inquiry: instruments for measuring science skills in primary education. *Research in Science & Technological Education*, 36 (4), 413-439.

DOI: [10.1080/02635143.2017.1421530](https://doi.org/10.1080/02635143.2017.1421530)

## **Contributions:**

Patricia Kruit reviewed the literature, collected and analyzed the data and drafted the various versions of the paper. The research team further consisted of Ron Oostdam, Ed van den Berg and Jaap Schuitema, who together supervised Patricia Kruit. The research team collaboratively conceptualized and designed the study and discussed the various steps of the research. The supervisors contributed to the interpretation of the outcomes, and reviewed and checked the paper.

**Chapter 4 is published as:**

Kruit, P. M., Oostdam, R. J., van den Berg, E., & Schuitema, J. A. (2018). Effects of explicit instruction on the acquisition of students' science inquiry skills in grades 5 and 6 of primary education. *International Journal of Science Education*, 40 (4), 421-441.

DOI: [10.1080/09500693.2018.1428777](https://doi.org/10.1080/09500693.2018.1428777)

**Contributions:**

Patricia Kruit is the first author of this article. She reviewed the literature, collected and analyzed the data and drafted the various versions of the manuscript. The research team for this article further consisted of Ron Oostdam, Ed van den Berg and Jaap Schuitema, who were the supervisors of Patricia Kruit. The research team collaboratively conceptualized and designed the study, deliberated about the data analysis and its outcomes. The supervisors audited the analysis and interpretation of the data and contributed to reviews and revisions of the manuscript.

**Chapter 5 is based on:**

Kruit, P. M., Oostdam, R. J., van den Berg, E., & Schuitema, J. A. (2018). Performance assessment as a diagnostic tool for science teachers. *Research in Science Education*.

DOI: [10.1007/s11165-018-9724-9](https://doi.org/10.1007/s11165-018-9724-9)

**Contributions:**

As the first author, Patricia Kruit reviewed the literature, collected and analyzed the data and drafted the various versions of the manuscript. The research team for this article further consisted of Ron Oostdam, Ed van den Berg and Jaap Schuitema, who were the supervisors of Patricia Kruit. The research team collaboratively conceptualized and designed the study, discussed the data analysis and its outcomes. The supervisors contributed to the analysis and interpretation of the data and reviewed and revised the manuscript.



# SAMENVATTING

## Inleiding

Wetenschap & Techniek (W&T) neemt in het primair onderwijs in de meeste landen een belangrijke plaats in. Doel van onderwijsbeleid is innovatie te versterken door het W&T onderwijs te verbeteren en meer mensen naar banen te trekken in de wetenschap, techniek en wiskunde. W&T onderwijs is erop gericht leerlingen te ontwikkelen tot wetenschappelijk geletterde burgers. Dat betekent onder andere dat leerlingen natuurwetenschappelijk denken ontwikkelen door te ervaren hoe kennis wordt gegenereerd, verbeterd en gevalideerd door middel van natuurwetenschappelijk onderzoek. In het basisonderwijs is er daarom toenemende aandacht voor het aanleren van onderzoeksvaardigheden in de W&T lessen en is het aanleren van deze vaardigheden als leerdoel opgenomen in de schoolcurricula.

In de praktijk blijkt het echter lastig om de leerdoelen voor onderzoeksvaardigheden concreet te implementeren in de lessen W&T. De focus ligt vaak op de praktische aspecten van onderzoek, zoals observeren en metingen doen, maar veel minder op de cognitieve aspecten, zoals het trekken van conclusies gebaseerd op resultaten. Daarnaast worden in het basisonderwijs de onderzoeksvaardigheden doorgaans onderwezen door middel van onderzoekend leren. De aanname die hieraan te grondslag ligt, is dat leerlingen door het zelf uitvoeren van een experiment gaandeweg onderzoeksvaardigheden aanleren en tegelijkertijd leren begrijpen hoe de wetenschap in elkaar zit. Alhoewel er bewijs is dat leerlingen ook onderzoeksvaardigheden leren door doen, lijkt steeds meer onderzoek erop te wijzen dat expliciete instructie effectiever is. Dat betekent dat met name bij basisschoolleerlingen die op het gebied van onderzoek doen onervaren zijn, onderzoeksvaardigheden beter op systematische wijze kunnen worden aangeleerd.

In dit promotieonderzoek is nagegaan in hoeverre een expliciete instructiemethode effectiever is dan leren door doen, wat de gangbare praktijk is in de meeste W&T lessen op basisscholen. Om de effecten van beide methodieken te onderzoeken zijn verschillende meetinstrumenten ontwikkeld en is de psychometrische kwaliteit onderzocht.

Er worden in dit proefschrift vier verschillende studies beschreven. De eerste studie betreft een beschrijving van het instructieraamwerk (een set ontwerpprincipes) dat gebruikt is om experimentele lessenseries te ontwerpen. De tweede studie bespreekt de betrouwbaarheid en validiteit van de verschillende meetinstrumenten waaronder zogeheten 'performance assessments'. In de derde studie worden de effecten van de

experimentele interventies geanalyseerd en besproken. Ten slotte gaat de vierde studie in op het gebruik van performance assessments als diagnostisch instrument voor de docent.

### **Studie 1: het instructieraamwerk**

In de eerste studie is een instructieraamwerk ontwikkeld waarmee lessen ontworpen kunnen worden voor het aanleren van onderzoeksvaardigheden via expliciete instructie. In het instructieraamwerk wordt uitgegaan van drie verschillende vaardigheden die ten grondslag liggen aan het toepassen van onderzoeksvaardigheden, namelijk natuurwetenschappelijk-specifieke vaardigheden (zoals het maken van een grafiek), algemene denkvaardigheden (zoals het analyseren van data) en metacognitieve vaardigheden (zoals het monitoren en evalueren van de taakuitvoering).

Eerder onderzoek liet zien dat het lastig is voor leerlingen om de verschillende typen vaardigheden in complexe W&T taken geïntegreerd toe te passen. Om die reden maakten we gebruik van de uitgangspunten van het *4C/ID model* (van Merriënboer, Jelsma, & Paas, 1992): grote, complexe leertaken worden gecombineerd met kleinere eenvoudige deeltaken. De deeltaken hebben als doel specifieke vaardigheden aan te leren en te versterken, alvorens deze geïntegreerd toe te passen in een complexe taak. In de loop van een lessenserie worden de deeltaken en de complexe taken zorgvuldig opgebouwd qua moeilijkheidsgraad. Naarmate leerlingen de vaardigheden beter beheersen, wordt de ondersteuning en feedback tijdens de uitvoering van de taken langzaam afgebouwd tot het moment dat leerlingen een complexe taak geheel zelfstandig kunnen uitvoeren.

Om leerlingen voldoende structuur te bieden, wordt de opbouw van de lessen vormgegeven volgens de stappen van de empirische onderzoekscyclus:

1. het formuleren van een onderzoeksvraag
2. het formuleren van een hypothese
3. het opzetten van een experiment
4. het meten en noteren van data
5. het analyseren van resultaten
6. het trekken van een conclusie

In elke les voeren de leerlingen een compleet experiment uit dat gestructureerd is volgens de empirische onderzoekscyclus. Daarnaast krijgen zij in elke les steeds expliciete verdiepende instructie ten aanzien van een bepaalde stap en oefenen zij de betreffende stap (bijvoorbeeld het formuleren van een goede onderzoeksvraag) ook in de deeltaken

waarin eveneens aandacht is voor de verschillende typen vaardigheden die zij daarbij moeten toepassen.

De expliciete verdiepende instructie bestond uit uitleg van de docent, gevolgd door een klassengesprek over de wijze waarop de onderzoeksvaardigheden moeten worden toegepast. Tijdens het uitvoeren van de complexe experimenten kregen leerlingen begeleiding in de vorm van hulpvragen en geheugensteuntjes. De metacognitieve vaardigheden werden aangeleerd door telkens terugkerende vragen in het werkboek welke leerlingen stimuleren deze vaardigheden toe te passen. Bijvoorbeeld: Wat is het doel van dit experiment?, Volg ik nog steeds mijn planning?, Hoe is het gegaan?

Het instructieraamwerk biedt de mogelijkheid om op systematische wijze lessen te ontwerpen waarin onderzoeksvaardigheden expliciet onderwezen kunnen worden. In een pilotstudie bleken de lessen goed uitvoerbaar te zijn voor docenten in combinatie met hun dagelijkse lespraktijk. De leerlingen gaven aan de lessen bovendien leuk te vinden.

## **Studie 2: het meten van onderzoeksvaardigheden**

Eerder onderzoek liet zien dat het lastig is om onderzoeksvaardigheden betrouwbaar en valide te toetsen. Vaak wordt gebruik gemaakt van schriftelijke toetsen, maar deze hebben als nadeel dat ze het toepassen van specifieke onderzoeksvaardigheden bij een 'echt' experiment niet kunnen toetsen. Performance assessments (toetsen op basis van individuele mini-onderzoeken en een leerlingverslag) worden beschouwd als een meer valide manier om onderzoeksvaardigheden te meten, maar de scores op deze toetsen zijn niet altijd consistent.

In deze studie werd onderzocht in hoeverre de verschillende typen onderzoeksvaardigheden betrouwbaar en valide gemeten kunnen worden. Er werden verschillende meetinstrumenten ontwikkeld met uiteenlopende formats: een schriftelijke toets, drie performance assessments met elk een ander onderwerp (*Skateboard*, *Bungee Jump* en *Hot Chocolate*) en vragenlijsten waarbij leerlingen het toepassen van hun eigen metacognitieve vaardigheden ten aanzien van het uitvoeren, bewaken en evalueren van onderzoeksactiviteiten moeten beoordelen op een 3-puntsschaal (*nooit*, *soms*, *altijd*). Het betrof de metacognitieve vragenlijsten 'Junior Metacognitive Awareness Inventory' (Jr. MAI) (Sperling et al., 2002) en 'Science Meta Test' (SMT).

Om te onderzoeken of convergentie tussen verschillende toetsvormen kan worden verbeterd, zijn de schriftelijke toets en de performance assessments systematisch opgebouwd volgens de principes van de onderliggende vaardigheden en de stappen van de empirische onderzoekscyclus.

De resultaten na afname van de toetsen met 128 leerlingen uit groep 7 en 8 lieten zien dat de schriftelijke toets en de drie performance assessments voldoende betrouwbaar waren. Uit de samenhang tussen de scores van de schriftelijke toets en de drie performance assessments kon tevens worden afgeleid dat met deze toetsen dezelfde vaardigheden worden gemeten. Dit laat zien dat convergentie tussen verschillende toetsvormen verbeterd kan worden door dezelfde onderliggende systematische opbouw te hanteren. Daarnaast kon uit de resultaten worden afgeleid dat het door de systematische opbouw mogelijk is om in meer detail te kijken naar het vermogen van leerlingen om bepaalde onderzoeksvaardigheden toe te passen. Dit geeft gelegenheid om de toetsen ook formatief te gebruiken.

De twee vragenlijsten bleken wel voldoende betrouwbaar, maar minder geschikt om bij basisschoolleerlingen hun metacognitieve vaardigheden gedifferentieerd in kaart brengen: de gemiddelde score was hoog met zeer weinig spreiding. Dit is waarschijnlijk te wijten aan het beperkte vermogen van jonge leerlingen om hun eigen metacognitieve vaardigheden in te schatten. Het is denkbaar dat de groep 7 en 8 leerlingen de metacognitieve vaardigheden nog niet of onvoldoende beheersen, ook al denken ze zelf van wel. Een alternatieve verklaring is dat de 3-puntsschaal te weinig gelegenheid biedt voor de leerlingen om genuanceerd hun vaardigheden te beoordelen.

### **Studie 3: effect van expliciete instructie**

In deze studie werden de effecten onderzocht van twee verschillende lessenseries ontworpen op basis van het instructieraamwerk zoals beschreven in studie 1. Het onderzoek is uitgevoerd bij 705 leerlingen verdeeld over 31 groepen 7 en 8 van 12 basisscholen. De studie was opgezet om het effect te meten van een interventie waarbij leerlingen 8 weken lang expliciete instructie over onderzoeksvaardigheden kregen versus een conditie waarin de onderzoeksvaardigheden werden onderwezen volgens het principe van leren door doen zonder expliciete instructie. Hierdoor kon informatie over de toegevoegde waarde van expliciete instructie worden verkregen. Ten slotte werd een conditie toegevoegd met leerlingen die tijdens de interventie periode hun reguliere W&T lessen volgden. Binnen scholen werden de groepen willekeurig verdeeld over de drie condities (zie voor overzicht Figuur 4.2).

Bij de leerlingen werden de onderzoeksvaardigheden gemeten door middel van de toetsen die ontwikkeld zijn in studie 2. In de voormeting werd een schriftelijke toets, een performance assessment (*Skateboard*) en een vragenlijst (Jr. MAI) voor het meten van metacognitieve vaardigheden afgenomen. Na de interventie periode waarin 8 lessen

werden gegeven kreeg een deel van de leerlingen ( $n = 467$ ) een schriftelijke toets, twee performance assessments (*Bungee Jump* en *Hot Chocolate*) en beide metacognitieve vragenlijsten (Jr. MAI en SMT) voorgelegd. Het onderwerp van de performance assessment *Hot Chocolate* kwam overeen met het onderwerp Warmte & Temperatuur van de interventielessen. Met het onderwerp van de performance assessment *Bungee Jump* waren de leerlingen onbekend.

De resultaten lieten zien dat de lessen van beide experimentele condities hebben gezorgd voor een verbeterde toepassing van onderzoeksvaardigheden in het performance assessment *Hot Chocolate*. Echter, de leerlingen die les hadden gekregen via expliciete instructie bleken het ook beter te doen bij het performance assessment *Bungee Jump* waarvan het onderwerp niet in de lessen aan bod kwam. Deze resultaten wijzen erop dat lessen het toepassen van onderzoeksvaardigheden kunnen verbeteren als er op systematische wijze voldoende mogelijkheden voor leerlingen worden ingebouwd om de vaardigheden te oefenen, maar dat systematische en expliciete instructie nodig is om dieper leren van de vaardigheden te bewerkstelligen, waaronder het toepassen van de vaardigheden in andere contexten.

Er is geen grote vooruitgang gemeten met de schriftelijke toets. Dit zou kunnen samenhangen met de toetsvorm: de schriftelijke toets bestond uit voornamelijk meerkeuzevragen en enkele open vragen. Dit betekent dat de schriftelijke toets minder lijkt op de uitvoering van een echt onderzoek zoals het geval was bij zowel de performance assessments als bij de experimenten die in de lessen van de interventie werden uitgevoerd. Hierdoor waren de leerlingen wellicht minder goed in staat het geleerde toe te passen in de schriftelijke toets.

De vragenlijsten lieten geen toename van de metacognitieve vaardigheden zien. Een mogelijke verklaring is dat leerlingen hun eigen metacognitieve vaardigheden bij de voormeting mogelijk hebben overschat waardoor er geen vooruitgang is gemeten. Desalniettemin zou het kunnen dat hun metacognitieve vaardigheden wel degelijk zijn verbeterd en hebben gezorgd voor hogere scores van de performance assessments in de nameting.

#### **Studie 4: performance assessment als diagnostisch instrument**

In de laatste studie werd de bruikbaarheid voor docenten onderzocht van de performance assessments als diagnostisch middel om instructie in de klas richting te geven. In het algemeen besteden docenten meer tijd en inspanning aan summatieve toetsing dan aan het formatief volgen van de vooruitgang van hun leerlingen. Informatie over de

voortgang die hun leerlingen maken is belangrijk voor het evalueren en het bijstellen van hun eigen instructie in de klas en voor het ondersteunen en het geven van feedback op het leerproces van de leerlingen.

De performance assessments zijn steeds systematisch opgebouwd aan de hand van de stappen uit de empirische onderzoekscyclus. Door naar de scores te kijken die leerlingen behaald hebben kan een gedetailleerd beeld worden verkregen van de leerlingprestaties voor de afzonderlijke stappen. Om een beeld te krijgen van typische fouten die gemaakt worden, is vervolgens gekeken naar voorbeelden van antwoorden door individuele leerlingen.

In het algemeen lieten de scores zien dat de performance assessments voor deze groep 7 en 8 leerlingen moeilijk waren. Niet elke stap uit de cyclus was voor hen even moeilijk. De leerlingen vonden het bijvoorbeeld moeilijker om een onderzoeksopzet te maken dan om een hypothese te formuleren. Er waren ook verschillen tussen de performance assessments zelf: in *Bungee Jump* en *Hot Chocolate* waren de gemiddelde scores voor de stap van het meten en noteren van data hoger dan in *Skateboard*. Alhoewel leerlingen over het algemeen relatief laag scoorden, was er binnen elke stap uit de cyclus wel veel variatie in de scores. Dit was vooral het geval bij het opzetten van een experiment, het analyseren van resultaten en het formuleren van een conclusie. De antwoorden lieten zien dat het ontwerp voor de experimenten niet erg gedetailleerd was en belangrijke informatie miste die nodig is om te begrijpen hoe het experiment uitgevoerd zou moeten worden. Bij het analyseren van de data hadden leerlingen moeite om hun conclusies daadwerkelijk te baseren op de door henzelf gemeten data.

Op basis van deze bevindingen kan geconcludeerd worden dat de manier waarop performance assessments geïmplementeerd en geanalyseerd worden, door de docent gebruikt kan worden om informatie te krijgen over de ontwikkeling van de leerling. Deze aanpak laat zien met welke stappen leerlingen met name veel moeite hebben. Hiermee kunnen docenten hun instructie en activiteiten in de klas aanpassen. De antwoorden van leerlingen kunnen gebruikt worden om meer specifieke en gerichte feedback te geven.

Deze studie laat zien dat het inzetten van performance assessments als diagnostisch middel in de klas van toegevoegde waarde kan zijn voor zowel in kaart brengen van voortgang van de leerlingen als om docenten te ondersteunen bij het evalueren en verbeteren van hun W&T onderwijs.

### **Beperkingen, suggesties voor verder onderzoek en aanbevelingen voor de onderwijspraktijk**

In het laatste hoofdstuk worden de belangrijkste bijdragen van dit proefschrift gepresenteerd, gevolgd door beperkingen van het onderzoek en suggesties voor vervolgonderzoek. Ten slotte worden aanbevelingen voor de onderwijspraktijk besproken.

Het proefschrift heeft twee belangrijke opbrengsten. Ten eerste een effectieve aanpak om onderzoeksvaardigheden aan te leren en ten tweede verschillende toetsvormen waarmee de onderzoeksvaardigheden gemeten kunnen worden. Een van de toetsvormen, performance assessment, is ook bruikbaar om problemen van leerlingen te diagnosticeren en daarmee instructie in de klas te optimaliseren. In het onderzoek wordt een quasi-experimentele opzet toegepast met een groot aantal leerlingen in reguliere onderwijscontext. Hierdoor voldoet het onderzoek aan empirische standaarden met tegelijkertijd een hoge ecologische validiteit.

### **Beperkingen en suggesties voor verder onderzoek**

In het onderzoek zijn onderzoeksassistenten (studenten van de universitaire pabo en afgestudeerde docenten) getraind om de lessen te geven. Het voordeel daarvan is dat de uitvoering van de lessen beter kon worden gecontroleerd dan wanneer de eigen docenten het zouden geven. In vervolgonderzoek zou gekeken kunnen worden naar het effect van de lessen als ze gegeven zouden worden door de reguliere groepsdocenten van scholen.

Een ander punt van aandacht betreft het gebruik van vragenlijsten om de metacognitieve vaardigheden te meten. De vragenlijsten waren eenvoudig af te nemen bij deze grote groep leerlingen, maar zij bleken niet in staat om een goede inschatting te maken van hun eigen vaardigheden. In vervolgonderzoek zou gekeken kunnen worden naar andersoortige methodieken om metacognitieve vaardigheden van leerlingen te meten, zoals observaties, docentbeoordelingen of hardop-denken protocollen.

Ten slotte is gebruik gemaakt van performance assessments die zeer gestructureerd waren. Voor vervolgonderzoek is het interessant om onderzoeksvaardigheden eveneens te trainen en te meten met behulp van open onderzoeksopdrachten waarbij leerlingen zelfstandig keuzes moeten maken en meer inbreng hebben in de keuze van onderwerp en uitvoering van een experiment.

## **Aanbevelingen voor de onderwijspraktijk**

Ten eerste adviseer ik docenten om leerlingen niet alleen experimenten te laten uitvoeren puur als leuk en motiverend onderdeel van W&T lessen, maar om net zoveel aandacht te besteden aan het aanleren van onderzoeksvaardigheden als er nu besteed wordt aan inhoudelijke kennis over natuurwetenschappelijke fenomenen. Het is belangrijk om deeltaken en steeds complexere experimenten zorgvuldig op te nemen in het W&T programma, tot de leerlingen in staat zijn om alle vaardigheden zelfstandig en geïntegreerd toe te passen. Daarnaast adviseer ik docenten feedback te geven en gerichte vragen te stellen waarmee de leerlingen hun taakuitvoering kunnen monitoren en evalueren, zodat de metacognitieve vaardigheden van leerlingen ontwikkeld worden.

De tweede aanbeveling betreft het instructieraamwerk. Het instructieraamwerk biedt een handzame leidraad voor docenten en onderwijsontwikkelaars om lessen te ontwerpen en onderwijzen waarin onderzoeksvaardigheden aangeleerd worden. Bovendien biedt de categorisatie van onderzoeksvaardigheden in drie onderliggende vaardigheden mogelijkheden om de lessen te integreren met het reken- en taalonderwijs op de scholen. Algemene denkvaardigheden en metacognitieve vaardigheden zijn immers belangrijke vaardigheden die niet alleen in de lessen W&T, maar ook bij andere vakken geleerd en toegepast kunnen worden. Niet alleen zal dit bij kunnen dragen aan een stevigere positie van W&T onderwijs in de basisschool, maar leerlingen zullen er mogelijk ook baat bij hebben als algemene denkvaardigheden en metacognitieve vaardigheden in meer verschillende vakken worden toegepast en geoefend. Een breder aanbod aan taken waarin de vaardigheden worden toegepast zou kunnen leiden tot een beter begrip en toepassing ervan in leertaken in het gehele curriculum.

Ten derde adviseer ik docenten om het toetsen van de onderzoeksvaardigheden niet te beperken tot schriftelijke toetsen met uitsluitend meerkeuze of open vragen. Performance assessments zijn niet alleen meer valide, maar kunnen tevens dienen om de vooruitgang op de diverse onderzoeksvaardigheden beter zichtbaar te maken. Dit heeft als voordeel dat docenten hun instructie kunnen aanpassen en specifieke problemen bij het leren kunnen aanpakken.

Ten slotte wil ik opmerken dat één van de deelnemende scholen in Amsterdam de expliciete instructiemethode in hun eigen W&T curriculum heeft opgenomen. De school heeft eigen docenten getraind om de lessen te geven en leerlingen uit groep 8 worden ingezet om leerlingen uit lagere groepen te helpen bij het uitvoeren van de experimenten in deze lessen. Dit laat zien dat het proefschrift heeft bijgedragen aan kennis over de effectiviteit van lessen gericht op de ontwikkeling van onderzoeksvaardigheden, maar daarnaast ook relevant en bruikbaar is voor de echte onderwijspraktijk.



# DANKWOORD

De grootste dank gaat natuurlijk uit naar alle kinderen die zo enthousiast hebben deelgenomen aan dit onderzoek. Hun docenten wil ik bedanken voor de gastvrijheid en het vertrouwen dat zij ons gegeven hebben om hun leerlingen les te geven.

Ilse Wassenaar, bedankt voor je goede ideeën bij het ontwerpen van de lessen. Anke van der Veen en Miranda Wolse, dank voor het uitproberen van alle lessen en jullie feedback. Dienneke Blikslager, bedankt voor het zo enthousiast uitzetten van de lessen in je school. Leuk om zulke topdocenten aan het werk te zien met mijn materiaal!

Mijn bijzondere dank gaat uit naar alle onderzoeksassistenten die met veel toewijding en inspanning de lessen hebben gegeven en toetsen hebben afgenomen en beoordeeld. Anke, Lykke, Suzanne van den Bergh, Jamie, Jill, Layla, Sara, Manon, Romy, Samira, Sander, Simone, Daan, Zinzi, Jaël, Suzanne Arends, Wesley, Ramona, Simone en Dienneke, jullie hebben met engelengeduld en pedagogisch inzicht met de kinderen gewerkt en daarnaast is het jullie gelukt om je te houden aan de vereisten die bij experimenteel onderzoek komt kijken. Dankzij jullie enthousiasme, betrokkenheid en flexibiliteit was het mogelijk om het onderzoek op deze schaal uit te voeren.

Ruben Fukkink, jouw methodologische ondersteuning heb ik bijzonder gewaardeerd. Ik heb je vaak lastig gevallen met allerlei vragen en altijd nam je de tijd voor een uitgebreide en zeer heldere uitleg.

Mijn lieve kamergenoten en mede-promovendi Eline, Aisa, Hessel, Liz, Rosa, Jannet, Fiona, Huub en Marloes wil ik bedanken voor alle steun, hulp en een luisterend oor in de moeilijke momenten, maar vooral voor jullie vriendschap en de luide gesprekken in de "stiltekamer".

Lieve Eline en Rosa, ik ben blij en vereerd dat jullie mijn paranimfen willen zijn. Mee buffelen tot het eind!

Het secretariaat van het kenniscentrum dank ik zeer voor alle ondersteuning. Irene en nichtje, bedankt voor het inpakken van al die dozen met materialen voor de scholen. Een enorme klus die ik nooit in mijn eentje gedaan zou kunnen hebben.

Mijn bio-collega's, dank voor het meejuichen bij belangrijke mijlpalen tijdens het onderzoek. Freke, dank voor je geduld, begrip en het meedenken op momenten dat ik het onderzoek voorrang moest geven. Marco, fijn dat je weleens een extra les kon overnemen. Evelien, bedankt voor het vertalen van toetsvragen. Wouter, dank voor het besteden van je tijd aan het meedenken over de toetsen. Jouw inbreng is van grote waarde geweest.

Mijn promotor Ron Oostdam en copromotoren Ed van den Berg en Jaap Schuitema wil ik bedanken voor hun kundige begeleiding. Zonder jullie grote betrokkenheid bij mijn onderzoek en het delen van jullie expertise en ervaring zou dit proefschrift niet geworden zijn zoals het nu is.

My dear sister-in-law Natasha, I am very grateful for the time you invested to thoroughly read and revise my thesis. Adrian, heel veel dank dat ik gebruik mocht maken van je tekentalent. Emma en Laura, fijn dat jullie vele uren achter het kopieerapparaat wilden staan om alle werkboekjes in te scannen. Arnold, bedankt voor je immer kritische kijk op zo'n beetje alles. Pap, bedankt dat je geen moment onbetuigd laat om te laten merken dat je trots op mij bent.

Arnold, Emma en Laura, jullie zijn de enige echt constante variabele geweest in het hele onderzoek. Dank daarvoor!

