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Review

Literature review: The role of the teacher in inquiry-based education

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A B S T R A C T

Inquiry-based education receives much attention in educational practice and theory, since it provides pupils and teachers with opportunities to actively engage in collaboratively answering questions. However, not only do many teachers find this approach demanding, it also remains unclear what they should do to foster this type of education in their classrooms. Our research question was: *Which teaching strategies are used by K-12 teachers when promoting inquiry-based education in their classrooms and what are the reported outcomes?*
After searching for empirical studies on this topic, we examined 186 studies investigating different ways in which teachers can promote inquiry-based education. Analyses revealed varying teaching strategies, differing with regard to direction (teacher directed, student directed and mixed) and different perspectives of regulation (meta-cognitive, conceptual, and social regulation). Results show that important teacher strategies in metacognitive regulation are: focussing on thinking skills, developing a culture of inquiry, supporting inquiry discourse, and promoting nature of science; in conceptual regulation: providing information on the research topic and focussing on conceptual understanding; and in social regulation: bridging the gap between high and low achievers, organizing student learning in groups and focussing on collaboration processes.

Contents

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1. Introduction

Since the early 1960s there has been ongoing debate in the educational sciences on how to promote active learning in students. Bruner's seminal 1961 publication *The Act of Discovery* can be seen as the kick-off of this debate. Bruner opposed the then-dominant expository style of teaching and argued instead for problem-solving as the basis for learning and teaching. Since then, this idea has been investigated and scrutinised with respect to its potential as a teaching model, and criticised for its strong suggestion of sole learners discovering knowledge for themselves (Bruner, 1986, p. 127). Socio-constructivist approaches to learning and teaching re-interpreted the process of learning by problem-solving and inquiry as a social process of co-constructing knowledge, in which the teacher should play a crucial role. Gradually, the idea of inquiry-based education[2] became associated with the concept of guided co-construction (Terwel, van Oers, van Dijk, & van den Eeden, 2009).

The implementation of inquiry-based education in everyday classrooms, however, remains a problematic issue. Most research on learning by problem-solving focuses on analysing the quality of learning outcomes, rather than the circumstances that may promote effective inquiry-based education. In particular, there is a need for more understanding of the role of teachers in promoting inquiry-based education (see also Ben-David & Zohar, 2009). This review aims to evaluate research evidence pertaining to the role of teachers in inquiry-based education and thus contribute to understanding the potential effectiveness of this teaching approach in everyday primary and secondary classrooms.

Examining the literature, it is not clear under what circumstances inquiry-based education is effective (see also Donnely, Linn, & Ludvigsen, 2014). On the one hand, authors such as Kirschner, Sweller, and Clark (2006) state that inquiry-based learning is less effective than direct instruction, their main argument being the problem of the limited amount of (teacher) guidance (see also Klahr & Nigam, 2004). These authors conceive inquiry-based learning as a process characterised by minimal supervision. Consequently, they state that such approaches do not correspond with the cognitive architecture of humans. Because the complex environments of such approaches place heavy loads on the working memory of pupils, their learning will be poorer than in more guided learning situations. On the other hand, authors such as Hmelo-Silver, Duncan, and Chinn (2007) consider inquiry-based learning to be more effective than more traditional, teacher-directed forms of learning. In response to the article by Kirschner et al. (2006), they state that the types of scaffolding that teachers usually provide during inquiry-based learning decrease, rather than increase, pupils' cognitive load. Based on several studies, they conclude that inquiry-based learning with sufficient scaffolding has a positive effect on pupils' learning, more specifically on their knowledge development, reasoning skills, motivation and self-regulated learning. Lazonder and Harmsen (2016) looked more specifically into the role of guidance in contexts of inquiry-based learning and found facilitative overall effects of guidance on learning activities, performance success, as well as learning outcomes. Looking specifically at the role of the teacher, Furtak, Seidel, Iverson, and Briggs (2012) conclude from their meta-analysis of inquiry-based learning that teacher-led activities have higher effects on student outcomes than student-led activities. Alfieri, Brooks, Aldrich, and Tenenbaum (2011) reviewed

[2] We use the broad term ‘inquiry-based education’ to include all forms of education in which inquiry is a central element.

studies of discovery learning, and found that outcomes were mostly favorable for explicit instruction when compared with unassisted discovery, but also that enhanced discovery (e.g., giving feedback, worked examples, scaffolding, and elicited explanations) produced better outcomes than other forms of instruction.

In general, we can conclude from literature that it is not clear which teaching strategies in inquiry-based education can have positive effects on students' learning outcomes. In this article we reveal what can be learned from the research literature in the period 2003–2013 concerning how teachers can promote a process of inquiry-based education in a much broader sense. Specifically, this includes teacher-designed activities and materials to enhance pupils' learning effects, teachers' didactical and pedagogical behaviour in the classroom, and the way they function as models. The research question of this study was '*Which teaching strategies are used by K-12 teachers when promoting inquiry-based education in their classrooms and what are the reported outcomes?*'

2. Theoretical framework

Before we discuss the method we used to answer our research question and present the results of our study, we first illuminate different conceptual approaches related to inquiry-based education. In this review, the overarching term 'inquiry-based education' refers to classroom processes in which pupils address questions about the natural, cultural or material world, collect data to answer these questions, analyse these data and report a conclusion based on their research. However, since different specifications of inquiry-based approaches can be found in the academic literature, we discuss these first and afterwards distinguish between the different conceptualisations of research stadia that are frequently applied in inquiry-based classrooms. Finally, we examine common ideas regarding the role of the teacher, specifically how guidance can be distributed among teacher and students and the various roles of the teacher in inquiry-based education.

2.1. Different ways of implementing inquiry-based education

Various ways of implementing ideas of inquiry-based education are distinguished within different paradigms in the research literature. The most prominent approaches are (1) inquiry-based (science) learning; (2) problem-based learning and (3) project-based learning (as also described by Darling-Hammond et al., 2008). Problem-based learning and project-based learning are introduced only as specifications of the overarching term 'inquiry-based education' that is applied in this review study.

While many other terms with overlapping meanings are regularly used, such as dialogic inquiry (Wells, 1999), and inquiry-based teaching (Rutten, van der Veen, & van Joolingen, 2015), we limit ourselves here to a brief discussion of the three most prominent approaches and their effects.

2.1.1. Inquiry-based (science) learning

Most studies of inquiry-based learning focus on inquiry learning in science classrooms. "Scientific inquiry learning gives students an authentic understanding of the nature of scientific knowledge and is a powerful tool for developing scientific thinking strategies and deep understanding of science content" (Ben-David & Zohar, 2009, p. 1659).

In a recent meta-analysis, Furtak et al. (2012) concluded that there is no consensus within the domain of inquiry-based learning about the meaning of the term 'inquiry'. Nevertheless, in general the (scientific) inquiry process in classrooms is often conceived of as a simplified set of steps referred to as the 'inquiry cycle'. Thinking strategies are considered central to the (scientific) inquiry, since the understanding is that for thoughtful inquiry processes, students need to explicitly understand how scientists think and why they think in that way, not only what scientists do and think during the scientific inquiry processes. Based on a review of studies describing inquiry cycles, Pedaste et al. (2015) describe a synthesised inquiry-based learning framework consisting of orientation, conceptualization (questioning and hypothesis generation), investigation (exploration/experimentation and data interpretation), conclusion, and discussion (reflection and communication). Furtak et al. (2012) specify the concept in terms of two dimensions: the cognitive and social activities of students themselves, and guidance for students from the teacher, their peers or the curriculum. From their meta-analysis, they conclude that the mean effect size of inquiry-based science teaching was 0.50. Similarly, Jerzembek and Murphy (2013) and Minner, Levy, and Century (2010) conclude that inquiry-based instruction practices yield positive results on student outcomes. Some research on inquiry-based education includes the use of ICT. For example, Gerard, Varma, Corliss, and Linn (2011) reviewed studies on professional development in technology-enhanced science. One of their conclusions was that comprehensive programmes lasting longer than one year had a significant positive effect on students' inquiry-based learning experiences.

2.1.2. Problem-based learning

Problem-based learning is a specific approach to inquiry-based learning that was first developed in higher education contexts. While problem-based learning is founded on ideas originating from Piaget (1954), Bruner (1961) and Dewey (1910), the concept as we know it today originated in Canada in the 1950s and 1960s (Gijbels, Dochy, Van den Bossche, & Segers, 2005, p. 28). Originally developed for the context of medical education, it was later applied in a range of disciplines including economics, engineering and geology. A general feature of this approach is its focus on learning and teaching based on concrete problems (Gijbels et al., 2005).

Although the definitions of problem-based learning are wide-ranging, Barrows describes six core characteristics: (1) learning is student-centred; (2) learning occurs in small groups; (3) a tutor is present as a facilitator or guide; (4) authentic problems are presented at the beginning of a learning sequence before any preparation or study has occurred; (5) the problems encountered are used as tools to achieve the required knowledge and the problem-solving skills necessary to eventually solve the problems; and (6) new information is acquired through self-directed learning (Barrows, in Gijbels et al., 2005, p. 29–30).

In a meta-analysis of research in the context of problem-based learning, Gijbels et al. (2005) found that problem-based learning has statistically and practically significant positive effects on students' knowledge application. The effect of problem-based learning on students' knowledge base tends to be negative. “However, the effect is found to be strongly influenced by outliers, and the moderator analysis suggests that students in a problem-based learning environment can rely on a more structured knowledge base” (2005, p. 32). In similar vein, Hmelo-Silver (2004) concludes from her review of problem-based learning that there is considerable evidence to support claims that problem-based learning has positive effects on students’ flexible knowledge, effective problem-solving skills, and their skills in self-directed learning.

2.1.3. Project-based learning

Project-based learning shares some characteristics with problem-based learning, but there are differences too. In his review on project-based learning, Thomas (2000) defines project-based learning as a model in which learning is organized around projects, which are complex tasks based on challenging questions or problems. “PBL engages the students as active learners in a learning process characterized by recurrent cycles of analysis and synthesis, action and reflection” (Thomas, 2000, p. 61), which has similarities with the research cycles in inquiry-based learning.

The main difference between project-based and problem-based learning is *the project*, which may be organized in various configurations from a single activity lasting several weeks to an evolving activity to be completed over the course of the academic year or even two years (Mioduser & Betzer, 2008). Blumenfeld and her colleagues describe it as follows:

> project-based learning places students in realistic, contextualized problem-solving environments. In so doing, projects can serve to build bridges between phenomena in the classroom and real-life experiences; the questions and answers that arise in their daily enterprise are given value and are shown to be open to systematic inquiry (Blumenfeld et al., 1991, p. 372–373).

Additionally, Thomas (2000) points out that project-based learning is challenging for most teachers, and that students have difficulties with the self-directiveness of this approach, but also that it can enhance the quality of students' learning. Mioduser and Betzer (2008) describe project-based learning as “a pedagogical means for supporting the students’ knowledge acquisition and problem-solving process” (p. 60). They found that engaging in project-based learning significantly increased the formal and technological knowledge of students.

2.1.4. Conclusion on implementing inquiry-based education

Different ways of implementing inquiry-based education, which are common in scientific literature, have been discussed in this section. Within all of these approaches there are many studies that fit with the overarching definition of inquiry-based education used in this study, which focusses on classroom processes in which pupils address questions about the natural, cultural or material world, collect data to answer these questions, analyse these data and report a conclusion based on their research. The focus of the present review is on the role of the teacher in inquiry-based education. All studies that both fitted the definition and gave insight into the role of the teacher were included, irrespective of the name that authors chose themselves for the approach. These studies were analysed looking at the role of the teacher in terms of amount of teacher direction and type of teacher regulation.

2.2. The role of the teacher

As for the role of the teacher, there are two distinctions that are often used in the context of inquiry-based education: *amount of teacher direction* and *type of teacher regulation*. The first distinction refers to the amount of direction that teachers give in the process of inquiry: is it only the teacher who decides what students do, or does the teacher give students much influence on choices concerning their own inquiries (e.g., Donnely et al., 2014; Furtak et al., 2012)? Furtak et al. (2012) state that in reform-based science teaching, there are many transitions of responsibility of learning from teacher to student and back, as students are actively engaged in constructing understanding, rather than being passive recipients of scientific knowledge. Most often, studies differentiate between teacher-directed and student-directed inquiry, sometimes including a middle category of mixed direction. In teacher-directed inquiry, the teacher has decided on the questions to be investigated, how these are to be investigated, etc., while in student-directed inquiry, the students determine what they want to study, how they will do so and what they will present. In mixed directed inquiry, the teacher determines some aspects of the research, but there is also room for the pupils to make choices.

In general, Furtak et al. (2012) conclude from their meta-analysis that studies involving teacher-led activities had mean effect sizes that were about 0.40 higher than studies involving student-led activities. Hence, teacher direction in the process seems to be of great importance.

The second distinction looks more closely at the kind of direction the teacher gives. Based on the examined literature (see for example Furtak et al., 2012), we can distinguish between three types of regulation by teachers: (1) meta-cognitive regulation, (2) social regulation, (3) conceptual regulation. We present these separately, but in practice they are often closely intertwined and not explicitly aimed for by teachers.

Meta-cognitive regulation has to do with planning, monitoring and evaluation. Kuhn, Black, Keselman, and Kaplan (2000) stress the importance of exercises that encourage students to think about possible solutions on a meta-level. Manlove, Lazonder, and de Jong (2009) studied collaborative scientific inquiry learning and found that a tool that provided regulative directions by giving goals and sub-goals, and providing hints to achieve these goals and to monitor progress (for example by writing down intermediate results) had a positive influence on both initial planning and learning.

Social regulation centres on cooperative principles and has to do with guiding the social processes of problem-solving. Several authors (e.g., Kaartinen & Kumpulainen, 2002; Sawyer, 2004) found that collaboration has a positive effect on inquiry-based learning. Discussion in the classroom (e.g., exploratory talk, Mercer, 2000) has been found to enhance learning outcomes. Rojas-Drummond, Gómez, and Vélez (2008) have shown that pupils aged 10–12 performed better in reasoning and problem solving in an experimental condition with exploratory talk compared to a control group.

Conceptual regulation has to do with subject-specific knowledge and rules. In the context of ICT, Löhner, van Joolingen, Savelsbergh, and van Hout-Wolters (2005) found that modelling tools could be of use in an inquiry-learning environment. These authors discovered that the use of graphical representations leads to a better research process than the use of textual representations. Several studies illuminate the positive effects for pupils' learning outcomes when conceptual models are used in an inquiry process (see for example Terwel et al., 2009). Scaffolding has also been found to have a positive influence on inquiry-based learning (Hmelo-Silver et al., 2007; Simons & Klein, 2007).

In our review we aimed to discover how teachers deal with giving direction to students and engaging in different types of regulation, and how effective this is in enhancing pupil outcomes.

3. Method

3.1. Literature search

The review started with a systematic search for relevant literature in the databases ERIC, PsychINFO and Web of Knowledge. To include the Dutch context, we did a separate search with Dutch translations of the search terms in the database of Pedagogische Studiën [Pedagogical Studies], the only Dutch scientific journal on education, which is referenced in SSCI. Previous reviews on Problem-based learning (Dochy, Segers, van den Bossche, & Gijbels, 2003; and Jerzembek & Murphy, 2013) have provided us with a number of relevant and empirically confirmed search codes. Partly based on these reviews, we applied the following search terms:

Design based learning, design based teaching, dialogic inquiry, guided inquiry, inquiry based instruction, inquiry based learning, inquiry based teaching, inquiry classroom, inquiry competence, inquiry education, inquiry learning, inquiry teaching, PBL, problem based learning, problem based teaching, problem solving, project based learning, project based teaching.

AND ("children" OR "elementary education" OR "elementary school" OR "high school" OR "K-6" OR "K-12" OR "middle school" OR "primary education" OR "primary school" OR "pupils" OR "secondary education").

The research databases were searched for studies carried out between 2003 and July 2013, of which 693 emerged.

3.2. Inclusion criteria

We selected studies that met the following criteria:

- Empirical qualitative and quantitative research studies on inquiry-based education, conducted in authentic classroom situations. A classroom situation is considered to be authentic when students are taught by their own teacher during regular school hours;
- Including information on the role of the teacher in inquiry-based education;
- Involving children in K-12 schools;
- Published between January 2003 and July 2013. This study builds on previous reviews conducted in 2003 and 2004 (Dochy et al., 2003; Hmelo-Silver, 2004). We choose for a ten year period, since much has been written on inquiry-based education in these 10 years;
- Published in SSCI-referenced articles or accepted by the Dutch Interuniversity Centre for Educational Sciences (http://www.ico-education.nl/research/ico-accepted-journals).

Applying these inclusion criteria reduced our database to 186 studies.

3.3. Analysis

The procedure involved searching for both qualitative and quantitative research studies. There are some quantitative studies in the field of inquiry-based education, but most studies present qualitative descriptions of data. Combining these two types of studies in this review provided an opportunity to explore teaching strategies with regard to inquiry-based education in its different forms, determine the effectiveness of certain approaches to inquiry-based education based on quantitative studies, and to provide rich descriptions of effective approaches that are informative for both theory and practice.

We developed a coding scheme consisting of 25 codes, applying high-inference coding to two categories focussing on the role of the teacher, namely direction of inquiry (student-directed, mixed direction or teacher-directed) and type of teacher regulation (conceptual, social and meta-cognitive). For both of these categories, we thoroughly analysed studies that explicitly focussed on investigating these categories. These studies were selected and coded independently in terms of direction and regulation by two researchers, who discussed disagreements until consensus was reached. Direction of inquiry was determined by the influences that teachers and/or students had on decisions taken in the inquiry process. We selected studies for additional analysis in which more than one type of direction was coded, as we wanted to determine how the role of the teacher plays out in different approaches. Type of teacher regulation was determined by coding a teacher's metacognitive (planning, monitoring and evaluation of inquiry), social (guiding the social processes of student learning during inquiry-based education), or conceptual (subject-specific knowledge and rules that play a role during the inquiry process) regulation. In terms of type of regulation, we looked more specifically into those studies that give explicit information on what teachers did in each type of regulation and what effects this had on students.

To ensure a good overview of the field, we investigated various databases (including the only Dutch scientific journal on education, referenced in SSCI). Furthermore, we worked collaboratively on the development of criteria for inclusion, the development of the coding scheme and the analysis of the studies.

4. Results

In this section, the results of the analyses are discussed in separate steps. First, the characteristics of the studies in our data set are described to better understand the context of the studies. Then, the results are discussed with respect to the role of the teacher (i.e. direction of inquiry and regulation by the teacher).

4.1. Description of the data set

4.1.1. The inquiry-based education approach

First, we will give insight into the different terms used to describe approaches to inquiry-based education and the types of investigation that students participate in to show how inquiry-based education is conceptualized and operationalized in research studies. In the data set, the majority of the approaches under study are defined by the authors using (a variant of) the term ‘inquiry learning’ ($N = 132$). In 30 studies the authors named their approach ‘project-based learning’, while 23 studies used the term ‘problem-based learning’. In one study, problem-based learning and project-based learning were combined. Two studies were termed ‘design-based learning’. Students participated in different types of inquiry (Table 1).

In most studies, students were involved in experimental investigations such as comparing the growth of yeast populations in plain water and in a sugar solution (Moreno et al., 2005). Students also quite often conduct literature research using the Internet and books, for example searching for information about a specific topic such as “the history of Hong Kong and mainland China” (Chu, Tse, Loh, & Chow, 2011). Furthermore, students performed descriptive research projects, which included taking pictures of their food to investigate eating habits (Anastopoulou et al., 2012). In simulation research students used electronic learning environments to virtually investigate phenomena such as whether a potato or a lemon can be used as a battery (Foti & Ring, 2008). In some studies we could not find information about the exact type of inquiry the students

Table 1
Type of investigation the students participate in.

Type of investigation	Example	Context	N[a]
Experiments	Students try to find answers to questions by conducting experiments	Most often used in science education	49
Literature research	Students try to find answers to questions by searching in books, on the internet, in journals or in newspapers	Often used in language education and history	43
Descriptive research	Students try to find answers to questions by researching practices, for example by observing or interviewing	For example in thematic activities in which students investigate professions	28
Design research	Students make a design that helps to improve a practice	Often used in technical education	21
Simulations	Students try to find answers to questions by making simulations (e.g., in virtual reality)	Often used in computer education	10

[a] N = number of studies in which this type is described.

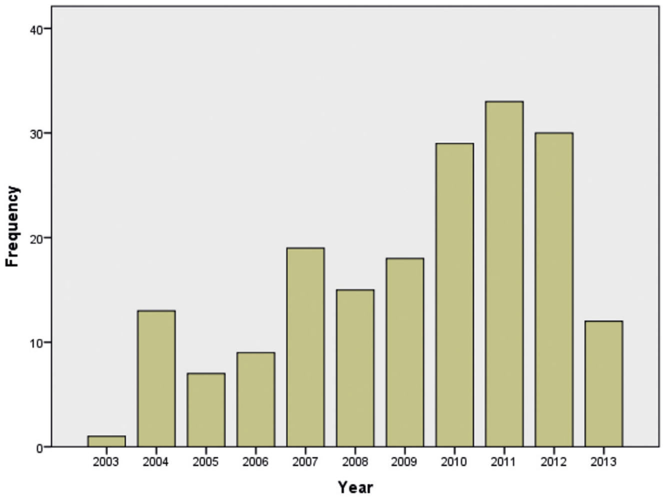

Fig. 1. Number of publications on the role of the teacher 2003–July 2013.

Table 2
Geographical contexts in which the studies were conducted.

Geographical context	North America	South America	Europe[a]	Africa[b]	Asia	Australia/New Zealand
Number of studies	102	1	49	2	27	5

[a] Includes 19 studies from Israel.
[b] Includes 1 study from Lebanon.

Table 3
Student age ranges.

Age [a]	4–8	9–12	13–15	16–18
Number of studies	34	81	69	44

[a] Studies that included more than one age range are included in each relevant category.

performed. In 53 studies, ICT was used to enable inquiry learning. Students' research projects lasted from one day to two years.

4.1.2. Publication trends and contexts of study

Next, it is interesting to look at the amount of studies dedicated to the role of the teacher in inquiry-based education and the countries where these studies were conducted to get insight into the research field. Scientific literature comprises many publications on inquiry-based education, but the role of the teacher in this type of education has become a more prominent research topic since 2010, as shown in Fig. 1.[3]Furthermore, the majority of the articles were published in journals of science education.

As shown by Table 2, studies were mainly conducted in North America (102 studies), which can be explained by the fact that inquiry is an obligatory part of the science curriculum of the United States. Furthermore, 49 studies were conducted in Europe (including Israel), 27 in Asia, five in Australia and New Zealand, two in Africa and one in South America. Of all studies, 166 report on the beta domain (science, biology, chemistry, mathematics), 18 on the gamma domain (history, economics, geography) and 12 on the alpha domain (language, the arts), with some overlap.

4.1.3. Participants in the inquiry approaches

Next, it is relevant to discuss the age of the students that are engaged in inquiry-based education. Table 3 shows the distribution across age groups. The overlap between the categories resulted from the multiple inclusion of a number of studies that studied children from more than one age group.

Because inquiry-based education has been found to be demanding for teachers, we were also interested in teachers' years of experience. While this information was unspecified in 94 studies, of the rest, 73 describe teachers with more than three

[3] The decline around 2013 can be explained by the fact that the search included publications until July 2013.

years of teaching experience, 28 describe starting teachers with less than three years of experience and 20 describe student teachers. Again, there was overlap between the categories for some studies.

4.1.4. Type of studies

In this review, different types of research studies were included, in which a multitude of instruments were used to measure different types of outcomes. The final dataset included evaluative studies, descriptive studies, design studies and one action research design (Table 4). Some of the studies fell into more than one category, mainly those combining evaluative and descriptive research.

In these studies, researchers collected different types of data sources (Table 5) using different instruments. They used observations to investigate what happened in the classroom and conducted interviews and/or administered tests to pupils and teachers. Questionnaires were applied and either the researcher or the teacher created logs or made notes. Student work, such as drawings or project documents, was taken into account in 61 studies.

Different types of student learning were assessed in the articles under study. Most of the studies ($N = 79$) tested students' knowledge, while 34 assessed students' skills and 38 measured students' attitude or motivation. In 31 studies an integrated way of assessing students' learning was used, mostly within an inquiry assignment.

4.2. Student and/or teacher direction

With regard to the direction processes during inquiry, three direction approaches were coded: student-directed inquiry, mixed direction, and teacher-directed inquiry (Table 6). These can be seen as three positions along a continuum from entirely student-directed inquiry to entirely teacher-directed inquiry.

As we were particularly interested in describing the differences in the role of the teacher, we looked more closely at studies in which more than one position on the continuum was taken into account ($N = 8$) and discuss these here, since they shed light on the influences of the different direction approaches on processes in the classroom and/or the results of these approaches.

4.2.1. Types of direction and effects of direction processes

Below, we describe the eight studies and elaborate on the different types of direction and the effects achieved. Table 7 sums up basic information on these studies. Information on validity and reliability was based on the information given within the articles themselves.

Biggers and Forbes (2012) conducted a study that included the full continuum from student direction to teacher direction. Student teachers were found to emphasise student-directed inquiry activities before their placement and define inquiry likewise, but they found it challenging to do so in their placement classrooms. Consequently, their definitions broadened to include more teacher-directed inquiry. Accordingly, they were more able to make decisions based on the needs of their learners by including the full continuum.

Lucero et al. (2013) distinguish three levels of teacher support that correspond with respectively teacher direction, mixed direction and student direction. Teachers reported whether they provided these different levels of support during different inquiry activities of their pupils, such as presenting results. Lucero et al. found that teachers prefer to share direction with their students, for example by interacting with the students to identify main ideas in new material. When teachers feel their environment enables them to be effective science teachers, they provide less support to their students and thus let students determine more for themselves (student-directed inquiry). Surprisingly, they also found that more teacher direction is reported in upper school years.

Zion et al. (2007) also took all three levels of direction into account. Teachers were given workshops on student-directed inquiry and subsequently implemented a two-year programme called 'Biomind', in which small groups of students work on inquiry projects. The authors identify three common factors that cause difficulties for teachers and recommend possible strategies for overcoming them. First, teachers lack scientific knowledge and understanding of the essence of the inquiry

Table 4
Study type.

Study type[a]	Evaluative, with control group	Evaluative, without control group	Descriptive	Design studies	Action research
N	43	46	89	16	1

[a] Studies that included more than one design type are included in each category.

Table 5
Instruments used.

Data sources[a]	Observations	Interviews	Tests	Questionnaires	Logs/notes	Student work
N	107	89	88	78	68	61

[a] Studies that employed a combination of instruments are included in each category.

Table 6
Direction of the inquiry process.

Direction approach	Role of teacher	Example	Overlap in direction approach			
			A	B	C	D
Student directed inquiry	Students determine what and how they want to study and what they will present. The teacher sets the stage and guides or facilitates the process if necessary.	Sadeh and Zion (2012) describe an investigation of the connection between air and soil temperature and the behaviour of ants: "students observed the ants, and observed differences between the ants' behaviour in the morning and during the afternoon. Based on the students' observations, they chose this topic and formulated the inquiry question." (p. 835).	x	x		x
Mixed direction	The teacher determines some aspects of the research, but there is also room for the pupils to make some choices.	"The problem-solving model of enacting the opening sections of an article involves presenting the students, before their first exposure to the article, with a problem similar or tangential to the one that the scientists are exploring and asking them to suggest suitable methods and experiments to solve it. During the ongoing collaborative process, students' answers are based on both their prior knowledge and inquiry skills and new, relevant information received from their teacher, according to the advancement of the solution." (Falk & Yarden, 2011, p. 79).	x	x	x	
Teacher directed inquiry	The teacher decides on the questions to be investigated, how these are to be investigated, and what needs to be presented.	"T he teacher explained to the class they were to do an investigation on the density of objects. The aim was to find out what objects float and what sinks in water and then to formulate a rule for flotation and sinking based on the density of the objects. The teacher distributed worksheets to students. The worksheet had a number of sub-headings dealing with the aim for the investigation, a list of required apparatus and materials, the procedure to be followed, a results table with headings, and a question, which related to the aim of the investigation. […] The teacher told the students they had 40 min in which to complete the investigation. She emphasized that they should read the instructions on the worksheet carefully before doing the investigation." (Ramnarain, 2011, p. 1360).	x		x	x

Studies with overlap in approaches:
A: Biggers and Forbes (2012); Lucero, Valcke, and Schellens (2013); Zion, Cohen, and Amir (2007).
B: Sadeh and Zion (2009, 2012).
C: Blanchard et al. (2010); Wong and Day (2009).
D: Bencze (2010).

process. Teachers can overcome this by, for example, participating in professional meetings and engaging in inquiry themselves. Second, students lack knowledge of biology, inquiry skills and scientific writing skills that are necessary for successful engagement in open inquiry. One way to overcome this is to train students in phrasing inquiry questions and linking these to phenomena. Third, time and other resources for conducting inquiry at school are limited, an obstacle that could be overcome by keeping teaching on a tight schedule.

Two other studies on the Biomind programme compared mixed direction and student-directed inquiry. Sadeh and Zion (2009) show that during mixed direction, the teacher determined the questions that students worked on and the way data were collected, but students were allowed to alter and revise the inquiry plan with the aid of the teacher. The teacher helped students in processing the data as well. In the context of student-directed inquiry the students determined their own topic, questions, data collection method and other parameters. The teacher had less overt influence, but did help the students, for example, with thinking about the best way to represent their data in tables. Sadeh and Zion (2009) concluded that student direction gained better results than mixed direction on two different parts of a dynamic inquiry performance index, namely in terms of 'changes during inquiry' (understanding the components of change) and 'procedural understanding' (understanding inquiry components and critical thinking). No significant differences were found on 'learning as a process' (understanding the importance of documentation and connection between inquiry questions and the importance of stages) or 'affective points of view' (understanding affective aspects of inquiry).

In a later study, Sadeh and Zion (2012) measured students' attitudes towards the inquiry projects. In the groups with student direction, the teacher directs and focuses the learning throughout the project, while in mixed direction groups, the teacher presents the phenomenon which the students will research, dictates their research question and explains how to gather further information. Students that directed their inquiry were more satisfied and believed that they benefitted from the project more often than mixed direction students, especially in cognitive domains. In terms of time, student-direction students spent significantly more time on the preparatory stages, graphically processing data and writing the discussion of their report, while mixed-direction students spent more time on documenting. Student-direction students also seemed to take more initiative and cooperate more with project partners than guided-inquiry students.

Blanchard et al. (2010) compared mixed direction with teacher-directed inquiry (more traditional, verification laboratory instruction). Blanchard et al. measured knowledge of content, procedure, and nature of science. They also provided teachers

Table 7
Basic information on studies concerning direction.

Authors	Country	Number of participants	Qualitative/ quantitative	Validity and reliability	Level of education
Bencze (2010)	Canada	78 student teachers	Qualitative	Member checks, data-, investigator-, theory- and methodological triangulation	Primary science and technology education
Blanchard et al. (2010)	USA	24 teachers/ 1705 students	Quantitative	Inter-rater reliability 0.78 on observations of teaching. Instrument for assessment of outcomes was agreed on by a panel, internal consistency: Cronbach's alpha 0.84.	Middle and high school
Biggers and Forbes (2012)	USA	6 student teachers	Qualitative	Data triangulation, Inter-rater reliability was approximately 85% before discussion, and 100% after discussion	Primary science education
Lucero et al. (2013)	Ecuador	173 in-service teachers	Quantitative	Content validity by basing scales on scientific literature and valid and reliable instruments. Crohnbach's alpha of the scales used was 0.75, 0.76, and 0.92.	Primary education
Sadeh and Zion (2009)	Israel	4 teachers/ 50 students	Quantitative and qualitative	Investigator triangulation, 93% agreement between judges, discussion until agreement	High school
Sadeh and Zion (2012)	Israel	13 teachers/ 295 students	Quantitative and qualitative	Closed questions: principal Component Analysis revealed three factors which accounted for 59.61% of the difference, with Crohnbach's alphas 0.81, 0.71 and 0.80. Open questions: inter-rater reliability 90%.	High school
Wong and Day (2009)	Hong Kong	1 teacher/75 students	Quantitative	One problem for students was judged by an expert panel, groups were equivalent in prior knowledge, pre-, post- and delayed posttest. Test items were not validated statistically, but since the same test was used for both groups, cross-sample item consistency was assured	Secondary science education
Zion et al. (2007)	Israel	10 teachers/ 190 students	Qualitative	Analysis of sensitizing concepts, as identified in literature, data- and investigator triangulation	High school

with intensive professional development programmes focussing on responding to student questions with questions, and therefore aimed at encouraging further investigation. Teachers of the mixed direction group used questions to guide students and helped them negotiate meaning, for example by referring them to background folders when they have questions. Teachers in the teacher-directed group were asked to explicitly tell students what they should do during the laboratory work and provide them with information. At both middle school and high school levels and regardless of level of poverty in a school, they found that students in mixed direction inquiry-based laboratory units, in which the teachers used more reform-oriented and inquiry-based practices, had significantly higher post-test and delayed post-test scores than students in traditional contexts.

Wong and Day (2009) compared a teacher-directed approach with an approach in which direction is mixed. In the first approach, the teacher lectured and prescribed practicums, while in the second approach the teacher presented a problem which the students investigated in small groups with the teacher acting as a guide and facilitator. He briefed these students about processes, roles and responsibilities that might be assumed by group members, as well as the distribution of study aids that helped them organize their research. He also asked them to make lists of what they needed to know, an action plan and possible solutions. Wong and Day compared the knowledge of the students in the two groups in a pre-test, post-test and delayed post-test, discovering that mixed direction was at least as effective as teacher direction and that the mixed direction students' comprehension and application of knowledge improved significantly over an extended time.

Bencze (2010) studied pre-service student teachers who were engaged in action research. Most of the student teachers investigated more closed-ended and teacher-directed projects. Bencze focussed on one student teacher of technology who conducted action research focussing on student-directed inquiry, by challenging students to build a device or structure that conserves heat. She provided them with some materials and posed probing, generic questions. This student teacher found this way of working to yield better results than more traditional practical activities (teacher-directed inquiry), with students developing better conceptual understanding. She concluded that it would have been better to first mentor the students in some procedural aspects. The student teacher underwent an interesting change of perspective, which led her to incorporate student direction into her practice.

4.2.2. Final reflections on direction of inquiry

We discussed eight studies in which more than one position on the continuum from student-directed inquiry to teacher-directed inquiry was taken into account. Looking at the effects of the different approaches to direction as far as this was researched in these studies, it appears beneficial for teachers to experiment with letting students direct some or all of the inquiry process themselves instead of engaging in teacher-directed inquiry (Blanchard et al., 2010; Sadeh & Zion, 2009, 2012; Wong & Day, 2009).

Likewise, from the results we can conclude that most teachers in these studies favour student direction or mixed direction over teacher direction (Biggers & Forbes, 2012; Lucero et al., 2013). However, studies do report that teachers seem to have difficulty implementing this (Biggers & Forbes, 2012; Lucero et al., 2013; Zion et al., 2007). Potential problems for teachers in implementing more student direction that were studied are a lack of confidence in their own knowledge of their particular discipline, students' lack of inquiry skills hampering their ability to work more autonomously, and the frequent shortage of time for teachers to prepare their classroom for this new way of working.

Given the reported benefits of student-directed and mixed direction, but also acknowledging problems that (student) teachers report with student direction or mixed direction, it seems important that teachers make decisions about the amount of direction that they give, based on their own competences, the needs of their learners and the demands of the inquiry activities that they want to implement. Consequently, it might be best for teachers that are new to inquiry-based education to differentiate along the continuum from student-directed inquiry on the one hand to teacher-directed inquiry on the other, instead of aiming for a single type of direction. In the following section, we discuss three types of regulation that can be part of the direction that teachers provide.

4.3. Types of teacher regulation

In this section, 24 studies that give insight into the types of regulation that teachers can apply are discussed. With respect to the regulation processes during inquiry, results can be categorized in the three types of regulation, as mentioned earlier: (1) meta-cognitive regulation, (2) social regulation, and (3) conceptual regulation (Table 8 shows descriptions of each).

The different types of regulation and their effects are further described and illustrated in the next paragraphs. We want to underline that these types of regulation will in practice be intertwined, but can be researched separately. Table 9 gives insight into some basic information on the studies. Some studies did not provide all information, we then used '?'. Information on validity and reliability was based on the information given within the articles themselves.

4.3.1. Metacognitive regulation

Teachers employ metacognitive regulation to teach students how to think and act as scientists. Within this broad category, teachers can focus on improving students' thinking skills, building a culture of inquiry in the classroom, guiding inquiry discourse in the classroom or making students familiar with the nature of science. Studies on each of these subcategories are discussed below.

4.3.1.1. Thinking skills. Metacognitive regulation is often discussed as an approach aimed at giving explicit attention to thinking skills, for example by discussing the development of a good research question or an action plan. Giving attention to thinking skills helps pupils to get insight into their thinking process. The following studies give insight into how teachers can encourage students to develop these thinking skills.

Ben-David and Zohar (2009) studied effects of explicit instruction in meta-strategic knowledge during inquiry learning using a quasi-experimental design. Students in both conditions worked on various scientific inquiry tasks. In the experimental group, teachers gave explicit instruction during two lessons on two strategies: defining research questions and formulating research hypotheses. They for example learned about the components of strong questions (clear variables). Students in the experimental condition outperformed students in the control condition on a test measuring application of the two strategies, with the effect of the experimental condition being stronger in low-achieving students than high-achieving ones.

The second study in which improving thinking skills is a central topic is done by Wu and Pedersen (2011), who examined timing of teacher-based meta-cognitive scaffolding in combination with computer-based scaffolding in a computer-based complex learning environment. The teachers encouraged students to engage in self-explanation by asking them questions about their inquiries and by asking peers to respond to the answers. Students were encouraged to think and were not given information indicating right or wrong answers. Teachers gave this meta-cognitive scaffolding either early in the inquiry process, immediately after students had thought about hypotheses, or later, when students were collecting and analysing their data. The authors found no statistically significant differences between early and late metacognitive guidance in terms of science knowledge nor on scientific inquiry skills.

Finally, Kyza (2009) investigated students' quality of reasoning about alternative hypotheses. Software, the task set-up and the teacher provided scaffolding. Students learned to create evidence-based discourse, but testing for alternative hypotheses did not play a central role in their research projects. Even when students paid attention to alternative hypotheses, they did not perceive them as important. Kyza concludes that teachers should give students additional and explicit scaffolding to teach them how to appreciate alternative hypotheses.

4.3.1.2. Culture of inquiry. Another way of providing metacognitive guidance is evident in classrooms with a focus on the establishment of a research culture. Studies in this area state that, compared to more traditional education, students should have a more active role in inquiry-based education. Various studies describe a tension between this new role and the more passive student role of traditional education (e.g., Kock et al., 2013) and discuss the role of the teacher in creating a culture of inquiry.

In a few studies, teachers explicitly communicated new expectations about students' roles in the classroom during inquiry learning. Smithenry (2010) describes a case study of an experienced teacher over the course of a year. She focuses on the manner in which teachers can make transitions in and out of guided inquiry. She uses a four step model: (1) preparation for guided inquiry using teacher-directed instruction to introduce new concepts, (2) transitioning into guided inquiry by

Table 8
The three regulative approaches, related roles of the teacher, examples and studies that explicitly focus on a specific approach.

Regulative approach	Role of teacher	Example	Studies with an explicit focus on the approach
Metacognitive regulation Focus is on learning to act and think as a scientist	Focussing on thinking skills	The teacher stimulates his or her students to engage in a process of self-explanation by asking them questions about their inquiries and by asking their peers to respond to the answers.	- Ben-David and Zohar (2009) - Wu and Pedersen (2011) - Kyza (2009)
	Promoting a culture of inquiry	The teacher explicitly communicates new expectations about student roles (more active) in the classroom.	- Enyedy and Goldberg (2004) - Kock, Taconis, Bolhuis, and Gravemeijer (2013) - Smithenry (2010) - van Aalst and Truong (2011) - Viilo, Seitamaa-Hakkarainen, and Hakkarainen (2011)
	Guiding inquiry discourse	The teacher teaches the pupils to use the 'Ask to Think-Tell Why' approach to stimulate children to ask thought-provoking questions such as 'How is … related to …? explain your answer'.	- Alozie, Moje, and Krajcik (2010) - Doucerain and Schwartz (2010) - Gillies, Nichols, and Burgh (2011) - Herrenkohl, Tasker, and White (2011) - Jennings and Mills (2009) - Mercer, Warwick, Kerschner, & Kleine Staarman (2010) - Viilo et al. (2011)
	Making students familiar with the nature of science	The teacher works with pupils in an actual laboratory and focuses on thinking about hypotheses, predicting results and analysing data.	- Akerson and Hanuscin (2007) - Ben-David and Zohar (2009) - Yacoubian and BouJaoude (2010)
Conceptual regulation Focus is on subject-specific knowledge and rules	Providing information on the research topic	The teacher starts a research project by asking the students to search for and write down everything they know about the object under study (with the help of internet, newspapers, asking parents).	- Bridle and Yezierski (2012) - Shymansky, Wang, Annetta, Yore, and Everett (2013) - Yeung (2010)
	Focussing on conceptual understanding	The teacher focuses on linking new information from the inquiry project to students' prior knowledge.	- Kock et al. (2013) - Rivet and Krajcik (2008) - Shymansky et al. (2013)
Social regulation Focus is on guiding the social processes of learning	Bridging the gap between high and low achievers	The teacher supports a low achieving student to become a more meaningful partner in group discussions.	- Rozenszayn and Ben-Zvi Assaraf (2011)
	Organizing student learning in groups	The teacher uses different strategies to form student groups, for example, when learning is directed at basic learning (without transfer) groups are assigned randomly but when learning is directed at more advanced learning, more mainstream students work in larger groups and advanced learners work in pairs.	- Apedoe, Ellefson, and Schunn (2012) - Cheng, Lam, and Chan (2008)
	Focussing on collaboration processes	The teacher determines and discusses with students the ground rules of collaboration before the projects start.	- Veenhoven and Stokking (2007)

establishing a non-authoritative teacher role; (3) students engaging in guided inquiry and (4) transition out of guided inquiry, for example by using a test to assess learning.

Several studies illustrate that both students and teachers need time to adapt to this new approach to teaching, and they discuss how teachers can facilitate this process. For example, van Aalst and Truong (2011) describe how a teacher introduced her students to knowledge-creation discourse while using a web-based inquiry environment. They started their research after working for five months on the development of a classroom ethos of inquiry and inquiry skills. For example, the teacher began by developing a knowledge creation contract which explicitly set out values and learning goals of inquiry teaching and which she used throughout the year to draw students' attention to learning goals of their inquiry projects. The teacher used a combination of tools to encourage students' discourse, including a knowledge wall, a forum and democratic whole-class talk. This research showed how students made progress in developing inquiry discourse and how they adapted to the new social structure of this discourse.

Table 9
Basic information on studies discussing teacher regulation (N = 24).

Authors	Country	Number of participants (teachers/ students)	Qualitative/ quantitative	Validity and reliability	Level of education (age)
Ben-David and Zohar (2009)	Israel	7/119	Quantitative	The teacher/researcher was observed to follow the protocols carefully, a reliable procedure was used to classify students, a ceiling effect prevented comparison on one hypothesis	Middle school (13–14)
Wu and Pedersen (2011)	USA	2/145	Quantitative	Each teacher administered each condition to their class. Items of the test were based on standards and reviewed by a subject expert. Cronbach's alpha for post-test score was 0.528. For the tasks, inter-rater reliability coefficient was 0.75. A survey reliably measured student satisfaction with Cronbach's alpha of 0.836.	Middle school science (13–14)
Kyza (2009)	USA	1/42	Qualitative	Data was examined by using both a theoretically driven and an empirical perspective.	Middle school (12–13)
Smithenry (2010)	USA	1/26	Qualitative and quantitative	Data triangulation. Member check. An iterative process was employed to go back to the data, check the validity of each category's definition against its content, resort and/or redefine the categories based on confirming and disconfirming evidence. Audit trail was maintained.	High school chemistry (15–17)
van Aalst and Truong (2011)	Hong Kong	1/16	Qualitative	External validity was improved by presenting the account of the researchers to other teachers and researchers. Agreement between the independent coders on notes was 0.95. Inter-rater reliability (Cohen's kappa) on questions was 0.82 and on ideas 0.78.	Primary school (9–11)
Enyedy and Goldberg (2004)	USA	2/54	Qualitative and quantitative	Initial conjectures were tested against multiple data sources for both confirming and contradictory interpretations. Other researchers reviewed interpretations of the cases in data analysis sessions, which produced additional evidence for an interpretation and alternative interpretations, which were tested against the data.	Middle school science (no age mentioned)
Viilo et al. (2011)	Finland	1/32	Qualitative	Inter-coder reliability of segmentation was 0.85, inter-coder agreement for classifying in 3 variables was 0.92 and for classifying the data across 20 variables was 0.88.	Primary school (10–12)
Jennings and Mills (2009)	USA	3/135	Qualitative	A team of five researchers, including the authors, worked in pairs to code sections of data, met regularly to discuss and revise codes, arriving at a final set.	Primary school (5–11)
Herrenkohl et al. (2011)	USA	2/50	Qualitative	Data triangulation.	Primary/Middle school (10–12)
Gillies et al. (2011)	Australia	? at least 18/? 35 groups	Qualitative	Observation schedule is based on one used in another study. Data triangulation.	Primary school (11–12)
Alozie et al. (2010)	USA	2/78	Qualitative and quantitative	Data triangulation.	High school science (14–17)
Doucerain and Schwartz (2010)	Canada	3/145	Quantitative and qualitative	Teachers reacted to the data. Questionnaire based on a validated questionnaire. For the interviews, an existing scale was applied. Data triangulation.	Middle school science (13–14)
Mercer et al. (2010)	UK	12/36	Qualitative	Analytic methods were based on prior research. Data triangulation.	Primary school science (?)
Akerson and Hanuscin (2007)	USA	3/33	Qualitative	Previously developed open-ended questionnaires were used. Triangulation of data sources from teacher and researcher perspectives. Each researcher developed profiles of the views of participants, which were compared to ensure reliability of the interpretive schema.	Primary school science (5–12)
Yacoubian and BouJaoude (2010)	Lebanon	1/38	Qualitative	A questionnaire has been administered that was validated in previous research. Data triangulation. A researcher and a judge examined students' responses; disagreements were solved by consensus, the percentage disagreement being 15%. Other data were checked by a second researcher, disagreements were solved by consensus.	Primary school science (11–12)
Rivet and Krajcik (2008)	USA	2/60	Qualitative	Reliability of over 90% between 2 scorers. Data triangulation.	Middle school science (13–14)
Kock et al. (2013)	The Netherlands	1/26	Qualitative	Data from various sources were used. A test was used that was translated from previous research.	Secondary school science (14–15)
Bridle and Yezierski (2012)	USA	1/54	Quantitative and qualitative	A published instrument was used that was previously found to have 100% validity and Cronbach's alpha of 0.78. For the interviews, authors attempted to obtain a representative sample by selecting participants with diverse conceptions.	High school chemistry (15–17)
Shymansky et al. (2013)	USA	300/212	Qualitative and quantitative	Cronbach's alpha coefficients for the scales in the observation protocols exceed 0.92. Combinations of data were used. Experienced test experts developed the observation instruments, questionnaires, and interview protocols and observers were certified by common training and calibration workshops.	Primary school science (8–12)
Yeung (2010)	Hong Kong	1/13		Self- peer- and teacher assessment of student performance.	

Table 9 (*continued*)

Authors	Country	Number of participants (teachers/ students)	Qualitative/ quantitative	Validity and reliability	Level of education (age)
			Qualitative and quantitative		High school Geography (17–19)
Rozenszayn and Ben-Zvi Assaraf (2011)	Israel	1/9	Qualitative	Findings and interpretations were questioned, internal and external validity was assessed, the effect of context and bias was taken into account, and the processes of analysis was displayed and discussed.	High school biology (17–18)
Apedoe et al. (2012)	USA	5/99	Quantitative	Existing instruments were used, internal consistency of the test was moderate, Chronbach's alpha was 0.47 for the pretest and 0.58 for the post-test.	High school chemistry (14–18)
Cheng et al. (2008)	Hong Kong	?/1921	Quantitative	Scales were based on earlier studies, Cronbach's alpha of the scale on group processes was 0.89, self-efficacy 0.82 and collective efficacy 0.85.	Secondary school (11–14)
Veenhoven and Stokking (2007)	The Netherlands	9/160	Qualitative and quantitative	Inter-rater reliability of the assessment: Jury alpha of between 0.70 and 0.96, Cronbach's alpha between 0.55 and 0.84. Experts, teachers and students deemed the pretest and posttest to be valid. Cronbach's alphas of the questionnaire of student perceptions of teacher behaviour were between 0.70 and 0.88. Jury-alphas within the same group were between 0.65 and 0.71. Assessment of learning interaction had Cronbach's alphas of 0.68 and 0.73.	Secondary school Geography (15–17)

Enyedy and Goldberg (2004) describe the implementation of a science curriculum unit, investigating how classroom discourse shaped two different learning communities. Through dialogue, the first teacher positioned herself as a co-inquirer, thus encouraging a culture of inquiry. The second teacher took a more authoritative position. The first teacher's students outperformed those of the second teacher on a post-test of scientific understanding and understanding of tools and procedures. Enyedy and Goldberg suggest that this could be an effect of teacher's behaviour.

Viilo et al. (2011) conducted a longitudinal ethnography to analyse teachers' efforts to support students in open, progressive inquiry in a collaborative learning environment. One research question concerned the use of tools and community members in establishing an inquiry culture in classrooms. This study offers an in-depth description of the teaching process of an experienced teacher. It shows how different strategies can be combined to promote an inquiry culture, including continuous assessment of the inquiry process, high expectations about research questions and explanation and guidance directed at making students' thinking visible. One of the tenets of this teacher's approach was to attach importance to collective decisions on how to proceed towards the aims of the project. This teacher also aimed to support students' own thinking and responsibility, to encourage them to formulate their own questions and problems and to ensure that team results would become available to the whole community.

4.3.1.3. Guiding inquiry discourse. There is ample research examining the development of a type of discourse intended to foster inquiry in the classroom. This is a subcategory of metacognitive regulation, because it describes how teachers explicitly regulate discourse in the classroom, thus mimicking the way scientists talk with each other. We found five articles that describe teacher behaviour aimed at the development of inquiry discourse.

In a longitudinal study by Jennings and Mills (2009), students were followed from kindergarten to fifth grade to examine how they co-constructed a discourse of inquiry. The authors describe how six interacting practices of inquiry work together to construct this discourse of inquiry (these include ‘Dynamic & Dialogic’ and ‘Attentive, Probing, Thoughtful’). Furthermore, they show how inquiry teaching is a complex process, which always requires a combination of teaching strategies. They conclude that research should not focus on a single aspect but look more broadly at combinations of different teaching strategies.

Herrenkohl et al. (2011) describe two teachers’ pedagogical practice over the course of one year as students carried out inquiry projects using the interactive website ‘Web of Inquiry’. This website provides students with an inquiry structure and scaffolds for performing complex inquiries and engages them in a process of metacognitive self-assessment. Qualitative in-depth descriptions show how teachers employed a wide variety of pedagogical practices, including a combination of metacognitive and social regulation. Both teachers employed strategies aimed at developing competing theories and alternative hypotheses. These included demonstrating the reasonableness of alternative hypotheses by carefully examining what makes hypotheses believable, developing experimental designs to test hypotheses (e.g., sharing ideas and discussing possibilities), analysing data to provide evidence (e.g., revoicing student ideas) and relating theories and evidence (e.g., students provide feedback to one another about their ideas). Students showed gains in inquiry skills such as linking hypotheses, formulating research questions and using investigation procedures.

Gillies et al. (2011) compared three strategies intended to teach students strategic and meta-cognitive questioning strategies during inquiry activities. They used a quasi-experimental design with two experimental and one comparison condition. The teachers in the experimental conditions guided the students to engage in more high-level discourse. In the cognitive questioning condition the teacher taught the 'Ask to Think-Tell Why' approach in order to encourage students to ask thought-provoking questions such as 'How is … related to … ? Explain your answer'. In the Philosophy for Children condition, teachers fostered the establishment of a community of inquiry in their classrooms. In the control condition, teacher guidance was geared to stimulating Collaborative Strategic Reading, which aims at comprehension of texts. In all conditions, students developed more helping discourses such as providing explanations, reasons and elaborations. The students in the cognitive questions approach scored better in reasoning and problem solving than those in the other conditions.

Alozie et al. (2010) also investigated teachers' guidance directed at the development of scientific discourse communities. These authors describe the use of curriculum supports, investigating the presence of a rationale behind the intended learning activities and discussions, teacher support in the curriculum in terms of strategies directed at the promotion of scientific discussions and the types of discussions for each lesson. They observed that, despite their intentions to promote inquiry, both teachers relied on traditional recitation strategies after all, thus failing to support the development of discourse communities as expected. The authors conclude that it is important to include teachers in thinking about curriculum materials.

In a two-year study, Doucerain and Schwartz (2010) investigated the effects of combining guided inquiry with extra teacher guidance in argumentation, with regard to students' conceptual understanding of conservation of matter in chemistry. Extra teacher guidance directed at structured discussions and debate was needed to make students' learning more effective.

With respect to guiding inquiry discourse in the classroom, some studies addressed the question of how teachers can use specific tools to stimulate discourse, such as the interactive whiteboard. Mercer et al. (2010) describe how the interactive whiteboard helps small groups of students in primary education to create 'dialogic space' for small-scale science investigations.

4.3.1.4. Promoting understanding of the 'nature of science'. There is a specific line of research focussing on the 'nature of science' (NOS), in which students learn to think about what actually constitutes science. While this can be seen as a specific strategy for metacognitive regulation, it is a more indirect form of regulation than the meta-cognitive strategies that focus directly on students' talk and thinking. The focus of two of these studies is directed at teacher behaviour specifically directed at students learning NOS.

Akerson and Hanuscin (2007) report on a study in the US that examined the impact of a three-year professional development programme on elementary teachers' NOS, their teaching practices and their students' NOS. Teachers developed more sophisticated ideas about NOS, for example, by becoming aware that there is no single scientific method. They also became aware of the importance of inquiry as a learning objective for their students, and were thus more motivated to use inquiry teaching in their classrooms. Teachers' explicit instruction in NOS resulted in positive changes in students' ideas about NOS.

Yacoubian and BouJaoude (2010) compared the effects of implicit and explicit teacher guidance directed at reflective discussions following laboratory activities, examining improvements in students' understanding of NOS. Student activities included thinking about hypotheses, predicting results and collecting and analysing data. After carrying out laboratory activities students had to communicate their findings to their classmates, after which the students in the experimental condition had to answer open-ended questions about NOS. These students discussed their answers in teacher-guided, whole-class discussions. This seemed to be more effective in developing students' understanding of NOS than implicit teacher guidance without whole-class discussions.

4.3.2. Conceptual regulation

Few studies established an explicit connection between specific teacher behaviour directed at conceptual learning and students' learning. Instead, most described more general evaluations of inquiry teaching, e.g. lessons in which teachers helped students by providing information on their research topic, and students' conceptual learning (for example, Bridle & Yezierski, 2012; Yeung, 2010). Some studies measured effects of a professional development path on students' conceptual learning (for example, Shymansky et al., 2013). Two studies focussed specifically on teacher regulation directed at conceptual learning. These studies are described here in more detail.

Rivet and Krajcik (2008) investigated the effectiveness of contextualized instruction during a 10-week science project. The two teachers implemented a holistic approach to project-based science, asking students to focus on the question 'Why do I need to wear a helmet while I ride my bike?' from multiple perspectives. Teachers paid particular attention to how students linked new information from the project to prior knowledge. The study showed that contextualized instruction had a positive effect on science learning, for which the authors had two possible explanations: the characteristics of the instruction, or the positive effect of this approach on student motivation (as an intermediate variable).

Although the next article is also an example of metacognitive regulation, as it is focussed on the formation of a culture of inquiry, we describe this article here, because its main focus is on conceptual understanding and regulation. Kock et al. (2013) based their research project on conceptual change. Students participated in activities in which current conceptual ideas were addressed, carrying out investigations to discover the rules for voltage, for example. Because student learning was limited, the researchers focussed on three areas of friction in the new curriculum that could explain the lack of success. First, they describe the conflict between open inquiry and students' need for guidance and structure. Second, they found that the students' awareness of discrepancies between their own theories and scientifically accepted theories did not lead to real understanding. Third, it is difficult to develop a scientific research culture within an existing school culture. This study recommends that inquiry assignments should offer enough structure for gathering experimental data upon which conceptual knowledge can be built. Students should also be given a theoretical starting point as a foundation for newly acquired understanding.

4.3.3. Social regulation

Since almost all inquiry-learning approaches make use of group work, social regulation is always a part of the process. However, this is rarely the focus of analysis and most studies describe this aspect in a rather indirect manner. Four studies make an explicit link between teachers' social regulation and students learning results.

Rozenszayn and Ben-Zvi Assaraf (2011) studied collaborative learning. In this case study, two student groups worked on open inquiries in a two-season project. The authors conclude that the role of the teacher was crucial in stimulating discussion among students regarding knowledge creation. The teacher had to bridge the gap between low and high achievers, for example by supporting a student who performed poorly and helping him to make a meaningful contribution to the discussions.

One practical question with regard to social regulation is how teachers should organize students into learning groups. Two studies address the composition of student groups during inquiry education. Apedoe et al. (2012) investigated how group size impacts chemistry concept learning, concluding that group size should be considered in combination with other factors. When the focus is on basic learning (without transfer), group size does not matter. But when the focus is on more advanced learning (with transfer), students in mainstream classes benefit from larger groups, while students in advanced classrooms learn better in pairs.

Cheng et al. (2008) investigated the role of group heterogeneity on project-based learning. They collected school examinations and student-report questionnaires on group processes, self-efficacy and collective efficacy. Group heterogeneity was measured by mid-term examination marks. Teachers used different strategies to form student groups, such as letting students choose their own groups, randomly assigning students, forming groups based on skill and ability levels, or instructing students to choose one group member and then combining these pairs into groups. Group processes such as positive interdependence, individual accountability, equal participation and social skills were found to be more important than group heterogeneity. High-quality group processes were more beneficial for both low and high achievers.

Veenhoven and Stokking (2007) investigated three types of teacher guidance: directed at research products, directed at the learning process of designing research, and directed at collaboration. Students' learning results were evaluated using a test and a questionnaire on their own perception of the intensity of teacher guidance and the quality of the collaboration. The results of the study did not meet expectations, since no relation was established between the first types of guidance and student performance. In the second assignment, teacher guidance directed at collaboration resulted in more productive interaction in the student groups. This kind of guidance included that teachers and students discussed ground rules for collaboration before the task and that during the task teachers intervened in the collaboration if ground rules were not followed.

4.3.4. Final reflections on teacher regulation

In this section we have described three types of teaching regulation during inquiry education: metacognitive regulation, conceptual regulation and social regulation. While these types of regulation could be clearly identified in many studies, only 24 studies were explicitly concerned with them. We have identified four main themes in metacognitive regulation (see also Table 8): focussing on thinking skills (Ben-David & Zohar, 2009; Kyza, 2009; Wu & Pedersen, 2011); developing a culture of inquiry (Enyedy & Goldberg, 2004; Kock et al., 2013; Smithenry, 2010; van Aalst & Truong, 2011; Viilo et al., 2011); supporting inquiry discourse (Alozie et al., 2010; Doucerain & Schwartz, 2010; Gillies et al., 2011; Herrenkohl et al., 2011; Jennings & Mills, 2009; Mercer et al., 2010; Viilo et al., 2011); and promoting nature of science (Akerson & Hanuscin, 2007; Ben-David & Zohar, 2009; Yacoubian & BouJaoude, 2010). Two themes were evident in the studies on conceptual regulation: providing information on the research topic (Bridle & Yezierski, 2012; Shymansky et al., 2013; Yeung, 2010); and focussing on conceptual understanding (Kock et al., 2013; Rivet & Krajcik, 2008; Shymansky et al., 2013). In terms of social regulation, three themes emerged: bridging the gap between high and low achievers (Rozenszayn & Ben-Zvi Assaraf, 2011), organizing student learning in groups (Apedoe et al., 2012; Cheng et al., 2008); and focussing on collaboration processes (Veenhoven & Stokking, 2007).

Taking a broad view of these studies on regulation, it becomes clear that both teachers and students need time to adapt to inquiry-based education and need to be facilitated in doing so. Moreover, we found that inquiry-based education is currently primarily seen as a social process in which interaction within the classroom plays a crucial role. This interaction needs to be facilitated and modelled by teachers, who find the task difficult and therefore benefit from professional development programmes that provide support for this role. Furthermore, the roles of both students and teachers are different in inquiry-based education and traditional education, and it seems important that teachers discuss this shift explicitly with their students. Metacognitive regulation seems to be most specific to inquiry-based education, as it is the specific focus of 17 of the 24 studies, and should aim to establish ideas about what research actually is and how it can be carried out. One precondition that will enable teachers to provide this type of regulation is that they themselves have well-developed ideas on these issues. The themes that we discovered in the three types of regulation illuminate which teacher activities are required in order to engage in inquiry-based education in the classroom.

5. Discussion

This review study examined 186 research studies carried out between 2003 and 2013 and focussing on inquiry-based approaches to learning for K-12. In our review, we concentrated on the teacher's role in inquiry-based education. To provide a comprehensive overview of the research field, we started out with reviewing all studies (N = 693) that examined active learning approaches geared to solving a problem, such as problem-based learning, project-based learning and inquiry-based teaching. After a strict application of selection criteria we ended up with 186 studies for the final review. The huge number of relevant studies illustrates what a high-interest field this currently is, particularly given the increasing number of studies published each year since 2010.

Taking a closer look at the types of studies conducted over the past ten years, we see that the vast majority have focussed on the science domain, with only a few reporting on either alpha or gamma subjects. Another finding is that the majority of studies report on practices in the USA. There have been large-scale, quantitative studies and smaller, qualitative studies. While inquiry-based education is mostly seen to be applicable to secondary and higher education, this review shows that more and more research is aimed at primary education.

5.1. Role of the teacher

Studies were classified as dealing with student-directed, teacher-directed, and mixed forms of direction. We reported more elaborately on eight specific studies that compared different divisions of direction between teacher and students. From an overview of these studies, it can be concluded that mixed or student direction has been found to give better results than teacher-directed inquiry (Bencze, 2010; Blanchard et al., 2010; Sadeh & Zion, 2009, 2012). However, this ought to be a cautious conclusion. Lucero et al. (2013) concluded that it would be better if teachers took a less prominent role in direction throughout the school career, but reached the opposite conclusion in their classroom studies. Hence, as established by Biggers and Forbes (2012), it seems plausible to conclude for now that differentiation along the continuum between student-directed and teacher-directed inquiry is most desirable.

As for types of regulation that teachers provide during an inquiry process, some of the studies focussed primarily on metacognitive regulation, while others concentrated mainly on conceptual regulation or on social regulation (Table 7). Although we distinguished analytically between these three types of regulation, it is important to bear in mind that they are closely intertwined in practice. Most of the studies that more specifically investigated teacher regulation, reported on meta-cognitive regulation, possibly because this type of regulation seems to be most applicable to inquiry-based education compared to other learning approaches. An underlying goal seems to be for both teachers and pupils to gain an understanding of what research is and how it should be conducted. This is a clear indication of the prominence of the National Research Council (e.g., National Research Council, 2012) in the US, which has led to a wealth of studies into teachers' and students' understanding of the nature of science and an underrepresentation of other research areas.

Meta-cognitive regulation is often combined with conceptual regulation; especially in studies reporting on the regulation provided by teachers aimed at showing how knowledge can be developed from inquiry. Social regulation is a topic on which much more research has already been conducted in the fields of cooperative and collaborative learning, leading to many conclusions about effective teaching approaches. Most studies find that interaction is very important in inquiry-based education and should be facilitated and modelled by the teacher. Many studies report that all of these elements require effort from teachers and more time for all participants to adapt to new roles and a new way of working.

Research in which teachers' meta-cognitive regulations were investigated in a more integrated way revealed four possible strategies for guiding inquiry-based education in students: focussing on thinking skills, developing a culture of inquiry, incorporating teacher guidance of inquiry discourse and paying attention to the understanding of the nature of science. In contrast to more direct forms of meta-cognitive scaffolding, which focus specifically on regulating students' actions or utterances, this form of guidance is directed at creating an optimal classroom environment in which students and teachers are encouraged to guide each other on the basis of science and scientific discourse.

These studies produce the following picture. Teachers should enculturate students to embrace inquiry and encourage them to act like academic researchers. The studies described here emphatically conclude that this is a complex and multi-dimensional process, which cannot easily be reduced to a few variables. It seems important for teachers to communicate clear expectations about students' new, more active role, which implies the emulation of researchers' activity on different aspects (Smithenry, 2010; van Aalst & Truong, 2011; Enyedy & Goldberg, 2004; Viilo et al., 2011).

On the basis of the studies reviewed here, it may be plausibly concluded that guiding inquiry discourse is an essential element in inquiry education. The different studies reviewed here demonstrate that it is indeed possible to support the enhancement of research and discourse skills, especially when different pedagogical practices are employed and guidance by an expert is available (Alozie et al., 2010; Doucerain & Schwartz, 2010; Gillies et al., 2011; Herrenkohl et al., 2011; Jennings & Mills, 2009).

Teachers should develop a better understanding of the nature of science, since this is an essential pre-requisite for inquiry-based education. Explicit instruction in the nature of science can result in a positive change in students' ideas about the nature of science (Akerson & Hanuscin, 2007). A combination of explicit instruction and whole-class discussion seems to be the most effective (Yacoubian & BouJaoude, 2010).

Although many studies included information about students' conceptual development, only two of them explicitly investigated the effect of conceptual regulation. The first (Rivet & Krajcik, 2008) found that contextualized instruction can be an effective approach for student learning in science subjects. The authors, however, could not determine whether this effect was a direct result of the characteristics of the instruction or was prompted by the positive effects of student motivation. The second study (Kock et al., 2013) gave insight into the initial difficulties facing a teacher and students who lacked experience with inquiry education, such as students' need for guidance, the discrepancies between the theories that students developed, and scientifically accepted theories.

Four studies investigated the effect of teachers' social regulation on student performance and revealed the importance of teachers' regulation of interaction processes in student groups (Apedoe et al., 2012; Cheng et al., 2008; Rozenszayn & Ben-Zvi Assaraf, 2011; Veenhoven & Stokking, 2007). These studies also provide useful suggestions of conditions that may moderate the effect of teacher guidance on the students' learning.

In this review, our focus was on the role of the teacher. The studies we evaluated all establish that the role of the teacher is very important for the successful implementation of inquiry-based education, and point out that this is a demanding role for many teachers to accomplish, due to the many facets involved. Nevertheless, a striking finding is that in the majority of studies the teacher was not involved in (co)developing interventions. Researchers tend to see teachers mainly as executors of interventions, and less as agents in the development of an inquiry-based approach in the classroom. For future studies, we think it is advisable to give teachers a more active role in the development of interventions, so that these are better attuned to educational practice. From our examination of these studies, we conclude that the role of the teacher is complex and that it is difficult to describe a single decisive element of that role. As Jennings and Mills (2009) state, 'Inquiry-based pedagogies are complex and multifaceted, difficult to sum up in any process, practice, or structure' (p. 1612).

5.2. Limitations

The biggest limitation to our review was the large diversity of reporting in studies, most of which lacked information on statistical measurements and/or concrete descriptions of teacher behaviour. Many studies stated only that a teacher had used an inquiry-based education approach, although there is barely any research on what this actually entails and which elements are crucial to enhancing students' development.

Another limitation of many articles is reporting on teachers' behaviour. Due to a lack of essential information and our choice of selection criteria, we could only include more detailed, qualitative descriptions of a selection of articles. As a result, a large proportion of the original 693 articles could not be included in the descriptions of teacher roles, even though they do give some information about teacher roles in inquiry-based education. However, because we screened the entire database several times during our analysis, we are confident that we have included those studies that were most relevant to our research question. All in all, the state of research literature on inquiry learning warrants care in drawing too strong conclusions.

Our focus of including both quantitative and qualitative studies in the broad domain of inquiry-based education meant that we are not able to statistically determine the effects of different teacher strategies on student outcomes. From our first analysis of the studies it became clear that there were not enough quantitative studies that applied similar teacher strategies and measured similar student outcomes for a meta-analysis. Moreover, we deemed it important to give in-depth insight into the strategies that teacher apply, and thus found it important to include qualitative studies in our review.

5.3. Further research

For future research, it is important to gain more insight into the preconditions for inquiry-based education, not just in terms of knowledge, but also in terms of the distribution of roles and of teachers' and students' understanding of what inquiry is. It would also be advisable for researchers in this field to look at teachers' classroom practices in more detail and especially the strategies they apply in enhancing inquiry-based education. Moreover, it would be worthwhile to place the initiative for formative interventions with teachers rather than creating programmes that teachers are supposed to teach.

Furthermore, besides experimental research, additional research is needed into other types of inquiry, including in the alpha and gamma domains. The added value of inquiry-based education in primary education also deserves more in-depth study. In terms of results, we advise future researchers report not only on cognitive measures such as language development or conceptual performances, but also on personal characteristics such as attitudes towards science, motivation, and the formation of an understanding of the concepts of academic research.

As yet there are few longitudinal studies measuring the results of inquiry-based education over the long term. This area offers interesting opportunities with regard to both subject matter learning and the development of an understanding of the nature of science and knowledge production.

In reporting on studies, it is advisable to present results in terms of means, standard deviation and effect sizes. The set-up of studies should enable multilevel analyses that include school climate and class culture as intermediate levels. This also opens the possibility for meta-analyses, which allow for more rigorous conclusions about the effects of well-guided inquiry-based education.

5.4. Practical significance

With respect to the results on direction of the inquiry process, we argue that teachers need time and support to facilitate their development towards new practices. It seems important for teachers to have sufficient knowledge of subject content and inquiry, but also for them to change their vision about inquiry, science and division of roles in the classroom. From our review, we conclude that the role of the teacher in inquiry-based education is complex, multi-faceted and demanding, but also worthy of research and practice, since it can create unique opportunities for future students in elementary and secondary schools to develop themselves as agentive inquirers.

This review is relevant for teacher education, as it illustrates the kind of preparation teachers need to foster inquiry-based education in their classrooms. We suggest that teacher education institutes prepare student teachers better for their role in inquiry-based education, for example by focussing attention on the different types of regulation and the themes that we have identified (Table 7). This preparation could entail student teachers experiencing inquiry-based education in their own teacher education programme. When working on an inquiry project themselves, teacher educators can help future teachers to become aware of how metacognitive, conceptual and social regulation affects their research and can also reflect on the effects of direction of inquiry by the teacher (educator) and/or student (teacher).

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