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Scaffolding Science Teachers in Open-inquiry Teaching

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RESEARCH REPORT

Scaffolding Science Teachers in Open-inquiry Teaching

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The present study deals with a school-based professional development trajectory for secondary science teachers, aiming at scaffolding teachers in open-inquiry teaching for the topic of water quality. Its design was based on the leading principle of 'guiding by scaffolding'. Seven experienced teachers participated in institutional meetings and teaching at school. The research focused on designing scaffolding tools, addressing these tools in the meetings, and implementing them in the classroom. The main research data were obtained from meetings, classroom discussions, and observations. The results indicated that the professional development trajectory has promoted teachers' learning of scaffolding students in open inquiry, especially the ability to know when and how to give students a well-balanced combination of 'structure' for open-inquiry learning and sufficient 'space' for that. The implications for science teacher education are discussed.

Introduction

A wave of science curriculum reform aiming at active and autonomous learning is occurring in many countries. A successful implementation of science courses, however, will require teachers to develop sufficient knowledge of new curriculum contents and methods, and appropriate competence to teach them. This puts new demands on the professional development of science teachers. From an extensive review of research on science teacher education, De Jong, Korthagen, and Wubbels (1998) concluded that it is important to develop courses that include strong relationships between course activities and teaching activities in the school in order to bridge the gap between pedagogical (content) theory and teaching practice. They also indicated that courses need to create a safe and supportive learning climate for teachers, and acknowledge that changing teachers' conceptions and teaching strategies is a process that takes its time.

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In the past decade, there has been a growing interest in the role of teacher networks or communities of practice (Wenger, 1998) for school-based professional development. Learning in a network context can reduce experienced teachers' existing resistance to change and innovations (Van Driel, Beijaard, & Verloop, 2001). It can also contribute to a growth in teachers' confidence in the value of their own practical knowledge by sharing them with colleagues and to an increase in willingness to experiment with ideas from colleagues in their own classroom (Adams, 2000). Networks can also facilitate the acceptance of new ideas and practices when the implementation is supported by materials that engage teachers in instruction and foster a sense of experimentation ('learning by doing'). This way of learning is also referred to as 'work-based learning' (Bailey, Hughes, & Moore, 2004) and facilitates teachers to become co-owners of the innovations (Putnam & Borko, 2000). Academic staff members can have a specific position in communities of practice, which however suffers from a dilemma: providing guidance and structure to teachers, in balance with facilitating teachers' construction of new classroom practices. This dilemma is analogous to the teacher's dilemma in the classroom (Richardson, 1992): ensuring that students learn expected subject matter content on the one hand, and empowering students to build on their own thinking on the other. This analogy is reflected in the congruence principle in teacher education (Korthagen, Kessels, Koster, Lagerwerf, & Wubbels, 2001), saying that teacher educators should treat teachers as they expect teachers to treat students ('practise what you preach').

In The Netherlands, a new curriculum reform for upper secondary education was launched in 1998. One of the central issues of this reform was promoting active and autonomous learning by students. Related to science subjects, it means, among others, that students should learn to carry out open-inquiry projects, including laboratory work and writing reports. In line with this, an open-inquiry assessment should be part of the final examinations. These innovations require a change in the role of teachers, from the usual instruction-oriented role to a more guidance-oriented role (Smits, 2003). Many teachers are not adequately prepared to implement open-inquiry settings and to help their students. This situation can also be found in other countries (Roydchoudhury & Roth, 1996). In order to support science teachers to implement the reform, a school-based professional development trajectory (PDT) was developed aiming at teachers' learning how to give students space as well as structure. Therefore, it focused on teachers 'guiding by scaffolding' in open inquiry. In this trajectory, upper secondary school science teachers and science teacher educators collaborated in a community of practice. The secondary school teachers' contribution to the community included preparing and reporting about guiding their students' open-inquiry learning, whereas contributions by the teacher educators included preparing and scaffolding the teachers in taking on their new roles. In the present article, a study of this trajectory on teaching for open-inquiry is presented.

The study was guided by the following central research question: 'In what ways can secondary science teachers be successfully scaffolded in open-inquiry teaching that combines giving space and structure to students?' The result of the study may contribute to a research-based design of supporting secondary science teachers in teaching for autonomous learning in science education.

Theoretical Framework

Inquiry in Secondary Science Classrooms

The extensive literature on inquiry in science education was recently reviewed by Lunetta, Hofstein, and Clough (2007). They found that inquiry is often described as the process of identifying problems and formulating questions, designing and planning investigations, collecting and analysing data, summarising results, reaching conclusions, and communicating the research. Teaching for inquiry learning may vary in the amount of autonomy given to students. At the one end of the continuum of student autonomy lies inquiry, in which the teacher provides a research question and gives explicit step-by-step instructions how to carry out the investigations (McDermott, 1996). At the other end of the continuum lies open-inquiry; that is, the teacher gives maximum opportunities to students to formulate their own research question, to design their laboratory activities, to generate their own interpretations of collected data, and so on (Berg, Bergendahl, Lundberg, & Tibell, 2003).

Traditionally, laboratory activities in the classroom are based on a 'cookbook' approach, thus hampering students to develop reflective thoughts on what they have done. Based on observations of dozens of classroom laboratory sessions by several teachers, Gallagher and Tobin (1987) found that high school teachers rarely asked students whether they understood what they were doing, why they were doing it, or what the results would show. Moreover, the teachers appeared to pay much more attention to laboratory reports than to the process of inquiring and interpreting data. Many teachers even dictated conclusions or wrote them on the chalkboard for students to copy. Hodson (1993) pointed out that practical work is often not taught very effectively, and even in laboratory settings few students have the opportunity to develop an insight into how to conduct investigations. In a large-scale study, Solomon, Scott, and Duveen (1996) showed that less than one-half of about 1,000 secondary school students were able to relate theory to an experiment that they had carried out.

Several scholars have shown that bringing students into a more open-inquiry environment (i.e. science laboratory teaching that leaves problems, answers, and methods of investigation more open to students), may stimulate them to learn much more autonomously how to do an investigation. Gibson and Chase (2002) pointed out that middle school students enjoy being involved in open-ended laboratory tasks, asking their own questions, finding ways to answer those questions, and realise the learning value of different inquiry approaches. Crawford, Krajcik, and Marx (1999) indicated that middle school students could improve their ability to ask good research questions and to connect questions with knowledge claims and evidence as they become more accustomed to open-inquiry learning. Roth (1994, 1995) and Hofstein, Shore, and Kipnis (2004) investigated open-inquiry and problem-oriented teaching–learning contexts, and found that most secondary school students had a remarkable willingness and ability to generate questions, to design and plan activities, to collect and analyse data, and to report the results. Hofstein, Navon, Kipnis, and Mamlok-Naaman (2005) found that an inquiry-laboratory group asked more questions in general and more higher-order questions than a control group of students.

Guiding by Scaffolding

The open-inquiry approach, compared with traditional classroom laboratory settings, demands new roles and responsibilities from students and teachers alike. In the teacher-centred 'cookbook' setting, the main role of the students consists of carrying out the prescribed activities. They have little control over problems and solutions. The role of the teachers consists of *guiding by prescribing* student activities, or, less restrictive, *guiding by modelling*; that is, by showing students how to handle experiments, how to interpret data, and how to reach conclusions. In the autonomy setting, however, students gain ownership of their investigations, for instance, by framing research questions themselves and looking for appropriate methods to find answers on their own. In the case of full autonomy, the teachers' role is *guiding by* laisser-faire; that is, offering students full space to organise their own activities. However, students have to learn to fulfil the autonomy role. When enabling them to assume this role, which would be beyond their unassisted efforts, the teacher's role consists of guiding in a way that is often called *guiding by scaffolding* (for an early use of this term see Wood, Bruner, & Ross, 1976).

The idea of scaffolding emerged from socio-constructivist views of learning, especially Vygotsky's (1978) socio-cultural notion of the 'zone of proximal development'. This zone reflects the distance between the actual development level of the learner as determined by activities that can be performed without assistance and the potential development level of the learner as determined by performance of tasks under guidance of a more capable person. This person guides the learner through the zone of proximal development towards a new actual development level in a gradual process of scaffolding. The broad idea of scaffolding is addressed extensively in the literature (Davis & Linn, 2000; Fellows, 1994; Mercer & Fisher, 1992). Scaffolding begins with establishing the learner's initial conceptions and goal conceptions, which is, in terms of Vygotsky (1978), clarifying the actual development level of the learner and the intended potential development level. Bliss, Askew, and Macrae (1996) identified a number of important scaffolds like giving approval, probing learner's ideas, structuring task activities, and providing general hints or specific suggestions that will help the learner throughout the task. Asking questions to the learner and using appropriate written materials are other important scaffolding tools.

Several studies report difficulties teachers have with scaffolding in science education. In a study of scaffolding problem-solving learning in the science laboratory, Reigosa and Jiménez-Aleixandre (2007) found difficulties related to excessive task demands, stereotype school culture reflecting procedural display rather than genuine problem-solving, and within-group interactions and roles. In a study of guiding students undertaking science investigations, Tomkins and Tunnicliffe (2001) warned of a scaffolding 'pitfall'; that is, the teacher can be so focused on teaching the intended learning goals that he or she hardly listens to students and does not give them intellectual space. However, they assert that much of students' classroom talk has a considerable learning value and should be used by the teacher when scaffolding. Another important source of difficulties is teachers' insufficient knowledge of and experience with scaffolding students (Bliss et al., 1996). In our experience, open-inquiry by scaffolding is difficult to carry out as the teachers are not prepared for the role of giving students space as well as structure and they do not see this role exemplified by their colleagues at school. This underscores the need to support teachers who want to implement open-inquiry settings in guiding students by scaffolding.

Framework of the Project

In the project we cooperated with science teachers from two secondary schools. With them, we discussed the opportunities for working in science teams within each school, combined with teaching activities for promoting autonomous student learning. A specific element of the science curriculum reform for upper secondary level was selected, the Final Open-Inquiry (FOI) task—a part of the new examinations. We agreed with the teachers to focus on preparing students for this assignment by doing a mini-FOI. The mini-FOI is an open-inquiry assignment comparable with the FOI but shorter in time (20 student-hrs instead of 80 student-hrs), and it deals with a specific theme. In the present project the theme was 'water quality'.

A school-based PDT for scaffolding teachers in open-inquiry teaching was developed. For this, scaffolding tools were designed for supporting teachers in finding a proper balance between offering students sufficient 'space' for open-inquiry learning on one hand, and sufficient structure for that on the other. So, 'guiding by scaffolding' was the leading principle that grounded the PDT. Four other ideas were included that had a supportive function. The idea of a 'community of practice' led to the establishment of a community in which different groups of participants took part: secondary school teachers from the biology and chemistry departments, and science teacher educators who acted as coaches as well as researchers. The participants shared their (practical) knowledge and experiences in a safe and supportive atmosphere. The teams of participating science teachers in the two schools were headed by a teacher-coordinator. The 'congruence' principle implied that the teachers who were learning to guide their students by scaffolding were supported by coaches who guided them by scaffolding. The coaches offered the teachers structure that was in balance with sufficient intellectual space to develop new knowledge and teaching practice. The idea of 'learning by doing' was elaborated as 'learning by teaching'. This meant that no formal course was offered, but that participants were invited to take part in a trajectory of activities in the school connected to the goals set, including the preparation of open inquiry lessons, teaching the lessons, and reflecting afterwards on the activities and the results in the light of the goals. Finally, the idea of making teachers 'co-owners of innovations' was elaborated as follows. The coaches made an inventory of teachers' concerns about the curriculum reform of 'open inquiry'. They constructed 'scaffolding tools'; that is, teaching materials intended to meet the concerns. The teachers were asked to adopt/adapt these tools for use in their classrooms, as scaffolding tools for their students.

The PDT activities were planned in four phases: orientation, in which the teachers set goals related to concerns they have about teaching for open-inquiry learning and activities that take these concerns into account (teaching a mini-FOI); preparation, in which the participants prepared their mini-FOI lessons; enacting, in which the mini-FOI was taught in the classroom; and evaluation, in which the participants reflected on their teaching and learning process. Each teacher spent about 50 hrs on this project: 12 hrs on attending PDT meetings; 10 hrs on teaching the mini-FOI lessons and giving feedback on student products; and the rest on preparation and development activities.

The PDT was accompanied by a study focusing on the ways in which science teachers can be successfully scaffolded in open-inquiry teaching. The framework of the project is summarised in Table 1. It shows that the project consisted of four parts with inter-related professional development activities, research activities, and the development of teaching materials. Each part was related to a specific research question. These questions are an elaboration of the central research question and are formulated as follows:

1. What are the teachers' concerns about open-inquiry teaching?
2. (How) Do the teachers adopt/adapt the scaffolding tools for classroom use?
3. (How) Do the teachers implement the scaffolding tools in the mini-FOI lessons?
4. (How) Do the teachers value the PDT, especially their experiences with the scaffolding tools?

Designing the Scaffolding Tools

Guiding by scaffolding is a general teaching principle, and from this notion a broad variety of general scaffolding tools can be generated, such as asking questions and hints for structuring task activities, but criteria for selecting appropriate scaffolding tools in specific situations are lacking (Bliss et al., 1996). In our study, we used the concerns identified with the teachers (see Findings section) as a starting point. Based on these concerns, we formulated three teacher learning goals. To guide teachers' learning process towards these learning goals, we designed three teacher scaffolding tools. We added a fourth learning goal based on the function of the mini-FOI: preparing students for the full FOI. The teachers should learn how support students in reflecting on their open-inquiry process. This learning goal was also accompanied by a scaffolding tool. The learning goals and scaffolding tools are presented in Table 2.

Table 1. Framework of project activities

	1. Orientation	2. Preparation	3. Enacting	4. Evaluation
PDT activities	Meeting 1: clarifying concerns; discussing mini-FOI as a common activity	Meetings 2–4: preparing mini-FOI lessons about the theme 'water quality'	Classroom practice: team teaching of the mini-FOI	Meeting 5: evaluation of the mini-FOI lessons and PDT
Research activities	Examining concerns → development of teacher learning goals	Examining discussions about the mini-FOI lessons, in particular about the scaffolding tools	Examining the implementation of the scaffolding tools in the classroom	Examining teachers' valuing of the PDT, especially their experiences with the scaffolding tools
Teaching materials	Scaffolding tools to be used in the PDT	Adapted scaffolding tools to be used in school classrooms		

Table 2. Teacher learning goals and scaffolding tools

Teacher learning goal	Scaffolding tool
1. Teachers are able to scaffold students in structuring open-inquiry	1. Scheme of general structure of the mini-FOI
2. Teachers are able to scaffold students in focusing on an open-inquiry issue	2. Focusing activities: the water jars task
3. Teachers are able to scaffold students in developing quality control of open-inquiry	3. Go/no go assessment worksheet
4. Teachers are able to scaffold students in reflecting on their open-inquiry process	4. Student peer assessment form

Scaffolding Tool 1 (ST1) consisted of a suggestion for the general outline of the open-inquiry project. For this, a scheme of the general structure of the mini-FOI was designed (see Figure 1). The teachers could use this scheme to scaffold students' learning when structuring their own open-inquiry activities.

Scaffolding Tool 2 (ST2) consisted of a hint for offering focusing activities to students. For this, a particular task for students (the 'water jars task') was designed (see Figure 2). The teachers could use this task to scaffold students' learning when designing their research question and research plan.

Scaffolding Tool 3 (ST3) suggested teachers to include go/no go assessment activities at the end of each phase of the inquiry. For this, a go/no go assessment worksheet was designed (see Figure 3). The teacher could use this worksheet to scaffold students' learning process by giving feedback, and, when necessary, to ask students to revise their activities or products.

Timetable	**Teaching and learning activity**
* Lesson 1; teachers A and B (2 hours in week nr. *x*)	* Orientation in groups on an interdisciplinary topic, resulting in a research question and a plan of experiments * Reflection: what did we learn about open-inquiry
* Homework (estimated time 2 hours)	* Selection and preparation of experiments * Studying relevant theory
* Lesson 2; teachers A and B (2 hours in week nr. *x + 1*)	* Execution of the experiments * Reflection on what we learnt about open-inquiry
* Homework (estimated: 2 hours)	* Data processing * Suggested conclusions
* Lesson 3; teachers A and B (2 hours in week nr. *x+ 2*)	* Formulating conclusions by the group * Preparation and presentation of a poster * Reflection on the mini-FOI as a whole: what did we learn about open-inquiry

Figure 1. ST1: scheme of general structure of the mini-FOI

The water jars task

- The teacher puts four jars on the demonstration desk, filled with green, turbid water; bright, transparent water; muddy water; water with some plants and small insects.
- The teacher asks the students to put the jars in order from 'good water quality' to 'poor water quality' and give arguments.
- The students discuss in groups
- In a plenary lesson, the teacher asks the groups to present their order, with arguments
- As a conclusion, the teacher focuses on the question of 'what do you mean with water quality; how do you investigate water quality?'
- The students reflect on the question of what the purpose of the activity was.

Figure 2. ST2: focusing activities—the water jars task

Scaffolding Tool 4 (ST4) consisted of a suggestion for offering reflection activities to students. For this, a student peer assessment form was designed to be used at the end of the open-inquiry; that is, after the poster presentations (see Figure 4). In addition, it was suggested that the teachers could ask questions to students, such as what did you learn about designing a research question, and how would you use that when doing the full FOI later on?

Teacher's decision for go/no go (at the bottom of the student worksheet of lesson 1)

* **Go**:	You can go on to the next task
* **No Go**:	Before going on to the next task, you should: (i) reformulate you research question, or (ii) add some experiments in your planning, or (iii) something else, viz. . . .

Figure 3. ST3: go/no go assessment worksheet

Questions for peer assessment

1. Has it become clear what the group's research question was about?
2. Has it become clear what the group has done to answer their research question?
   * What we found clear was ……
   * What we did not find clear was ……

Figure 4. ST4: student peer assessment form

Methods, Data Collection and Analysis

Two upper secondary schools were selected for participating in the project. Willingness of the teachers to cooperate in the science team was a main criterion for selection. From these schools, seven science teachers (referred to below as T1–T7), having 5–20 years of experience, participated in the project. The teachers were guided by two experienced science teacher educators who acted as coaches as well as researchers.

The study was characterised by a multifocal research lens (Borko, 2004) and a combination of qualitative and quantitative research methods (multi-method approach; Baxter & Lederman, 1999). Many aspects of learning in a community of practice were mapped, including individual teacher learning and group learning. Table 3 presents a summary of the data sources that were generated and collected in the different parts of the project. In Table 3, the number of pages of the transcriptions is indicated (page A4, single spaced). For each part, the methods of collecting and analysing the data are elaborated below.

Part 1: Orientation—identifying teachers' concerns

A teacher questionnaire was constructed, consisting of a question about the duration of their teaching experience, a question about the disciplines they were teaching, and the following open question: 'What concerns do you have about open-inquiry at upper secondary level?' In Meeting 1, the teachers completed the questionnaire and discussed their answers to the open question. The data collected in this project part were analysed focusing on concerns about teaching open-inquiry, on guiding students in particular. This was done by two researchers independently. Firstly, they analysed the written answers and the transcribed audio-recordings of the meeting by identifying teachers' concerns and clustering them into categories using an iterative procedure during which the data were constantly compared with each other. The notes of the researchers had a supportive function. Secondly, by comparing and discussing the analyses (investigator triangulation; Janesick, 2000), they aimed to reach consensus about the interpretation of the data. Thirdly, they presented the raw data and their interpretations to a third researcher for a final check. Issues raised were discussed until consensus was reached.

Table 3. Summary of data collection in the four parts of the study

Data collection	Project Part 1	Project Part 2	Project Part 3	Project Part 4
Teacher questionnaires (initial and evaluation)	x			x
Transcriptions of audio-taped PDT meetings	30 pages	100 pages		25 pages
Researchers' notes	x	x	x	x
Teacher products (e.g., teaching material, e-mails)		x	x	
Transcriptions of audio-taped mini-FOI lessons			180 pages	

Part 2: Preparation—adopting/adapting the scaffolding tools

The teachers prepared the mini-FOI lessons in three teams. As School 1 would teach the mini-FOI in two classes, it formed two teaching teams: one team of three (chemistry teacher T1 and two biology teachers T2 and T3), and one team of two (chemistry teacher T4 and biology teacher T5). School 2 formed one team: a chemistry teacher and a biology teacher (T6 and T7) for one class. In Meeting 2, the coaches presented the tools ST1 and ST2, and the teachers discussed adopting and adapting them for use in their classrooms. In Meeting 3, the teachers reported about their efforts to include the mini-FOI in the school timetable. Subsequently, tool ST3 was discussed. When Meeting 4 took place, the teachers of School 1 had already started the mini-FOI. These teachers reported on their experiences, in particular on problems with the 'go/no go assessment'. Improvements were discussed. Because of time constraints, tool ST4 was presented on paper only.

The data collected in this project part consisted of transcriptions of the audio-taped meetings, observer notes, and adapted teaching material. The analysis was carried out by two researchers independently. Firstly, they split up the transcriptions into parts, linking each part to the respective scaffolding tools. Secondly, they identified teachers' learning process in terms of the categories: discarding, adopting, or adapting the scaffolding tools. Oral and written arguments of the teachers were also analysed. The notes of the researchers had a supportive function. Thirdly, the adapted teaching materials were analysed to find out whether or not the issues of discussion were reflected in the adaptations. Finally, they compared and discussed the analyses applying the same procedure as described in project Part 1.

Part 3: Enacting—implementing the scaffolding tools

The three mini-FOI lessons of 2 hrs each were taught in three classes. All lessons were audio-taped by one of the researchers. The transcriptions resulted in about 20 pages text each lesson. After most lessons, the researcher had an informal review talk with the teacher teams and made notes of this talk. Again, the data were analysed by each of the researchers independently. Firstly, each of them identified the learning process of the teams in terms of discarding or using the adopted/adapted scaffolding tools in their lessons. Secondly, the ways of using them were also identified. The results obtained from the three teams were compared. The notes of the observers had a supportive function. Finally, they compared and discussed the analyses applying the same procedure as described in project Part 1.

Part 4: Evaluation—valuing the PDT

A teacher evaluation questionnaire was constructed, consisting of two sections:

- Section 1 on teachers' opinions of the amount of 'space' and the amount of 'structure' they had provided their students with (see Figure 5). These questions were asked after each of the three lessons;

Evaluation questionnaire about teachers' scaffolding in the classroom					
Your opinion on your scaffolding in the classroom					
	very few				very much
* how much 'space' did you provide your students with?	1	2	3	4	5
* how much 'structure' did you provide your students with?	1	2	3	4	5
Illustration of my answer:					

Figure 5. Questions from the teacher evaluation questionnaire, Section 1. These questions were asked after each of the three lessons

- Section 2 on teachers' opinions of their learning experiences (see Figure 6). These questions were asked after the preparation part of the project.

The data of Section 1 were processed by calculating the mean score on the space-item and the structure-item, respectively, for getting a measure for the openness and structuredness of the lessons as perceived by the individual teachers. Moreover, group mean scores for each lesson were calculated as well as overall mean scores. The data of Section 2 were processed by counting the number of ticks per topic.

In Meeting 5, an evaluative discussion was started by sharing the given answers and illustrations. The discussions were recorded on audio-tape and transcribed. The data were analysed using the same procedure as applied in project Part 1; this time the analysis categories regarded the amount of space and structure provided and the teachers' learning experiences.

Evaluation questions about teachers' learning experiences

By preparing the mini-FOI with colleagues and coaches, I learnt in particular about:
[tick 3 alternatives at most]
[ ] scaffolding students
[ ] assessing students
[ ] cooperation with colleagues from other science subjects
[ ] the input the students gave
[ ] cooperation between students
[ ] an aspect not mentioned yet, namely …..

Illustration of my answers:

Figure 6. Question from the teacher evaluation questionnaire, Section 2. These questions were asked after the preparation part and after the enacting part of the project

Findings

Part 1: Orientation—identifying teachers' concerns

Categorising the answers to the open question in the initial teacher questionnaire and the concerns that appeared in the discussions during Meeting 1, three main categories of concerns were identified (Table 4). We defined a category as a main category when at least three of the seven teachers expressed concerns in the category under consideration.

Part 2: Preparation—adopting/adapting the scaffolding tools

The results of project Part 2 are summarised in Table 5 and elaborated below. After some discussions that focused on 'understanding biology and chemistry' rather than on 'doing inquiry', the teachers accepted 'doing inquiry' as the aim of the mini-FOI; they adopted ST1 and adapted it to local circumstances. Actually engaging in some student activities themselves contributed to this result.

ST2 was introduced by having the teachers carry out the water jars task themselves. In the subsequent discussion, the teachers recognised that students often do not feel the need to focus when starting an open-inquiry. Students are willing to suggest a topic for inquiry, but encounter difficulties as soon as they have to formulate an accompanying research question and plan. The teachers concluded that students have to learn to cope with uncertainty at the start of an open-inquiry but are not likely to do so. Therefore, the teachers wanted to have a 'no-guidance phase' preceding the water jar task. They expected students to experience feelings of uncertainty, which would motivate them to learn strategies of coping with open-inquiry and to determine a focus. They wanted to present the water jars task as an example of such a strategy. Therefore, they adapted tool ST2 (see Figure 7).

The teachers adopted ST3 without change. They expected that it would facilitate the monitoring and would also improve the quality of students' mini-FOI results. One of the teachers expressed how he wanted to use it in the classroom:

> I want to give my students supporting points on the way. Well, a go/no go assessment is such a supporting point, you provide students with structure. (T3)

The teachers also adopted ST4 without change. They wanted to use it for evoking student reflection not only on the posters but also on the mini-FOI as a whole. They

Table 4. Teachers' concerns about open-inquiry in the classroom

Category of teachers' concerns	Number of teachers (N = 7)
1. How to guide students in structuring open-inquiry	4
2. How to guide students in focusing on parts of an open-inquiry task	3
3. How to monitor and assess students' progress	3

Table 5. Summarised results of project Part 2: preparation—adoption or adaptation of scaffolding tools by teacher teams

Scaffolding tool	Teacher Team 1	Teacher Team 2	Teacher Team 3
1. Scheme of general structure of mini-FOI	Adaptation to local circumstances		
2. Focusing activities: the water jars task	Adaptation by adding an introduction activity to evoke a need for focusing on research question and plan		
3. Go/no go assessment worksheet	Adopted		
4. Student peer assessment form	Adopted		

recognised the importance of having a reflective discussion at the end of each session. As one of them stated:

> At the end of each lesson, we should take time for evaluation. Together we should have a look at the completed worksheets and discuss what is good and what should be improved as all of us find reflection very important. (T7)

Part 3: Enacting—implementing the scaffolding tools

The results of project Part 3 are summarised in Table 6 and elaborated below. The teams implemented the tool ST1 as intended. They also implemented the adapted ST2 (focusing activities).

In Meeting 4, Team 1 and Team 2 reported that the students had asked what the 'no guidance phase' was good for. As a consequence, Team 3 (which started teaching the mini-FOI after this meeting) included reflection activities in the classroom by asking the students 'What was difficult for you in this assignment', resulting in a classroom discussion about the need for more focus, leading to the water jars task. Teacher T6 observed that this task did support students in focusing and said to his team mate:

The water jars task and its introduction

Phase 1: 'no guidance'

- The teacher presents the research scope using vague terms only, saying something like 'investigate water quality', without giving any explication
- Students brainstorm in small groups about how to proceed
- Classroom discussion aiming at expressing students' feelings of uncertainty and evoking a motive: how to start open-inquiry?

Phase 2: structuring and focusing

- The water jars task (see Figure 3)
- Reflection on strategies how to start open-inquiry

Figure 7. Adapted focusing activities (ST2)

Table 6. Summarised results of project Part 3: enacting—implementation of scaffolding tools in the classrooms

Scaffolding tool	Teacher team 1	Teacher team 2	Teacher team 3
1. Scheme of general structure of mini-FOI	ST1 implemented as intended		
2. Focusing activities: the water jars task	ST2 implemented as intended		*Idem*; reflection activities added
3. Go/ no go assessment worksheet	ST3 implemented partly	*Idem*; discussion on criteria for a 'go' assessment	ST3 implemented fully + discussion on criteria for a 'go' assessment
4. Student peer assessment form	ST4 implemented without evaluation of students' assessments	ST4 implemented with evaluation of students' assessments	ST4 implemented fully, focusing on quality criteria for posters

> It is nice to see how the jars task starts the discussion again. The process was not proceeding; they were at a loss what to do. Then I showed the jars and all groups came up with new ideas they had not yet thought of. (T6)

The teachers scaffolded the focusing towards a research question. An example of this is shown in the following transcript:

Student: Sir, we want to get water from an agricultural place and from a natural place. The amount of phosphate and nitrate and then the life in it. If it is polluted, has it to do with that.
Teacher 1: You know, the kind of research you want to do, if I am right, is the influence of a certain factor on something else. What is the influence of nitrate on
Student: on life
Teacher 1: Something like that. Go and think in that direction
Student: Yes, we want to investigate something
Teacher 1: Yes
Student: But what should we write down as a research question?
Teacher 1: The relation between the influence of this on that. Something like that. Just try.
Student: [look into a book of experiments] Let's look, 5 and 6 (experiments on phosphate and nitrate) and then look at living beings in the water

This transcript shows that T1 scaffolds students in formulating a research question by stating 'the influence of a certain factor on something else'. That results in students realising that they have to formulate a research question. This makes them become more concrete in what they want to measure.

The teams implemented the tool ST3 in different ways. Because of a lack of time, Team 1 discussed research questions and plans without ending up with a definitive go/no go assessment. Team 2 started the go/no go assessment, discussed in plenary the criteria for getting a 'go', but also did not finish the assessments because of lack of time, concluding:

> Everybody has advanced a good deal into the right direction. But if I would now have to give a go or no go, most groups would get a no go. There is a lack of focus. (T4)

Team 3, having heard the lack of time experienced by the other two teams, took sufficient time for the go/no go discussion. They made their criteria for a 'go' explicit, discussed the group products in plenary, and then did the go/no go assessment. They experienced that giving a 'no go' raised a need to assess the subsequent improvements as well.

Finally, the teams implemented tool ST4. They dealt with the results of the student peer assessments in different ways. The teachers of Team 1 opted for reporting about the assessment they had done themselves. They summarised the stronger and weaker points of the posters. The teachers of Team 2 opted for paying attention to students' assessment of the posters. Having heard the experiences of their colleagues, in a plenary lesson the teachers of Team 3 paid attention to quality criteria for reporting an open-inquiry on a poster and to a general discussion about what students had learnt from doing the mini-FOI.

Part 4: Evaluation—valuing the PDT

In the answers to the questionnaire, the teachers indicated that they perceived to have provided their students more with space than with structure (see Table 7, teachers' mean scores). There are some differences between individual teachers. In their opinion, the amount of space provided increased from the first to the last lesson, and the amount of structure decreased (see Table 7, group mean scores). Table 8 shows that during the PDT most teachers learnt in particular about scaffolding students and cooperation with colleagues from other science subjects. Moreover, a new aspect was mentioned by several teachers as an important learning experience: planning the inquiry by the students.

These learning experiences were elaborated in the discussion after the completion of the questionnaire. Working together helped them to shift their focus from content to the common aim of the mini-FOI, as is illustrated by the following quote:

> It was an eye-opener that we aimed at the same objectives. … we had the same approach towards students. Therefore I was able to transmit very clearly the aim of the mini-FOI to the students: this is an exercise. (T3)

The mini-FOI experiences had also, to some extent, resulted in changes of teachers' ideas about teaching in their usual lessons; for instance, using group work in open inquiry lessons more often.

The teachers found the scaffolding tools extremely instructive for them as well as for the students. They all expressed that, after this PDT, they would use them again in the mini-FOI, the full FOI, and in open-inquiry tasks in regular lessons. The teachers liked the general outline of the mini-FOI (ST1) and the different aspects incorporated in it, such as the planning in three lessons. They mentioned this structuring of the inquiry process as one of the strong aspects of the mini-FOI. They found that scaffolding students by focusing activities (ST2) should be a part

Table 7. Teachers' opinions on the amount of 'space' and 'structure' provided in their lessons

	Amount of 'space' provided (mean score)	Amount of 'structure' provided (mean score)
Teachers' mean scores on the space-item and the structure-item (see Figure 5)		
Teacher T1	3.5	3.5
Teacher T2	3.7	3.0
Teacher T3	–	–
Teacher T4	3.8	2.7
Teacher T5	3.8	2.7
Teacher T6	4.0	2.7
Teacher T7	4.8	3.0
Group mean scores (*N* = 6) on the space-item and the structure-item over lessons (see Figure 5)		
Lesson 1	3.8	2.9
Lesson 2	4.0	3.0
Lesson 3	4.2	2.5
1 + 2 + 3	4.0	2.8

teaching open-inquiry. They had learnt that students have to cope with uncertainty and that teachers should give a critical feedback to students' research questions and research plans at an early stage. The teachers said to have greatly appreciated working with go/no go assessment (ST3) in the mini-FOI. As one of them said:

> The go/no go is of great interest during the FOI. I did not succeed in giving every group a go/no go assessment but I did discuss the criteria in a plenary lesson. And what should improve to get a 'go'. (T6)

However, some teachers were concerned that the assessment would require more time for additional guidance and for a second assessment of the improved research

Table 8. Teachers' opinions of their learning experiences

	Teachers' ticking of topics (see Figure 6)	
Topic	Learnt during preparation	Learnt during enacting
Scaffolding students	5	4
Assessing students	1	2
Cooperation with colleagues from other science subjects	4	4
Input the students gave	2	3
Cooperation between students	2	3
Aspects not yet mentioned	3 (planning)	2 (planning)

Note: Data presented as number of ticks.

question and plan. They were enthusiastic about using the peer assessment form (ST4) and had noticed that students had been critical towards each other. As one of the teachers stated:

> Through the form, you give them glasses with which to look at the posters. I think that is very instructive. (T5)

The peer assessment form also helped teachers to promote reflection on the complete inquiry process. They had learnt that they should plan sufficient time for reflective student activities.

Conclusions, Discussion, and Implications

Conclusions

The overall research question of this study was: 'In what ways can science teachers be successfully scaffolded in open-inquiry teaching that combines giving space and structure to students?' In order to answer this question, a school-based PDT was implemented. It consisted of four parts: orientation, preparation, enacting, and evaluation.

Research question 1: what are teachers' concerns about open inquiry teaching?. Using the data obtained in the orientation part of the PDT, this question can be answered as follows. Three main teacher concerns about open inquiry teaching were identified. They were useful for designing three teacher learning goals and related scaffolding tools. A fourth learning goal and a connected scaffolding tool were added, related to the function of the mini-FOI in the curriculum. The teachers agreed to use the mini-FOI in their classrooms. In the preparation part of the PDT, the mini-FOI and the scaffolding tools were discussed by the teachers.

Research question 2: (how) do the teachers adopt/adapt the scaffolding tools for classroom use?. In the preparation part of the PDT, the teachers adapted ST1 to local circumstances, adapted ST2 by adding an introduction activity to evoke a need for focusing on designing a research question and plan, and adopted the two other tools (ST3 and ST4). Probably because they felt it could contribute to solve their concerns, they accepted the structure the coaches provided them (the scaffolding tools). By taking the space they got for adapting them, they got the opportunity to become owner of the adopted tools.

Research question 3: (how) do the teachers implement the scaffolding tools for classroom use?. This question was answered in the enacting part of the PDT. The teachers implemented the tools ST1 (scheme of structure of mini-FOI) and ST2 (focusing activities) in the mini-FOI lessons as intended. The teachers of the third team even added reflection activities to ST2. The two other tools, ST3 (go/no go assessment) and ST4 (student peer assessment), were partly implemented by the teachers of Teams 1 and 2 and fully implemented by the teachers of Team 3. It seems that, probably because of not adapting, Teams 1 and 2 had not become an owner of tools ST3 and ST4. Team 3 was better prepared for implementing these scaffolding tools because they taught the mini-FOI after being informed about the experiences with the tools by Teams 1 and 2.

Research question 4: (How) do the teachers value the PDT, especially their experiences with the scaffolding tools?. Finally, in the evaluation part, we found that the PDT was positively valued by the teachers. They had learnt in particular about scaffolding students, cooperation with colleagues from other science subjects, and planning open-inquiry. Over the lessons, they felt to have provided their students increasingly with space and decreasingly with structure. Although that order fits with teaching open inquiry, it may also reflect that the teachers learnt how to combine space and structure while teaching the mini-FOI. The teachers intended to use the scaffolding tools again in the mini-FOI, in the full FOI later on, and in open-inquiry tasks in regular lessons.

It is concluded that science teacher can be successfully scaffolded in open inquiry teaching by participating in a professional development trajectory that is designed as follows. First, the scaffolding in the PDT is made explicit by using scaffolding tools that combine giving space and structure to students. Second, the scaffolds are mainly based on teachers' concerns about open-inquiry teaching. Third, the teacher scaffolding tools are exemplary for scaffolding students. Fourth, the teachers get the opportunity to adapt the scaffolding tools for their students, to implement them in the classroom, and to evaluate experiences. Fifth, the PDT activities are embedded in a cooperative setting: team-teaching, exchange of experiences with colleagues from other schools, and guidance by coaches from university.

Discussion and Implications

The present study has shown that it is possible and fruitful to scaffold science teachers in open-inquiry teaching. The principle of 'guiding by scaffolding' is often applied by adults for guiding youngsters, but we have expanded this: a more educated adult (the coach) scaffolds less educated adults (the teachers). It is essential to define the 'zone of proximal development' of the less educated group and to agree about the learning goals. For that, we investigated the concerns of the teachers about the innovation of open-inquiry teaching. It appeared that such concerns can be used successfully as the main base for designing teacher learning goals and related scaffolding tools. It also appeared that a professional development trajectory can be successful; that is, the teachers learn how to scaffold students in open-inquiry, when the scaffolding tools have a double character: the coach uses them for scaffolding the teachers and the teachers can use them (if needed in an adapted form) for scaffolding their students in open-inquiry.

The success of the professional development trajectory can be explained by the synergy between the leading principle of 'guiding by scaffolding' and four supporting ideas. First, the idea of 'learning by doing' was not only applied in the meetings, learning by experiencing, and adapting the scaffolding tools, but also in the schools: learning by teaching in the classroom. This elaboration is in line with McBride, I Bhatti, Hannan, and Feinberg (2004), who stress the importance of engaging teachers in inquiry-based science in such a way that they can bring their new insights to their classrooms and implement the best ideas in their teaching. The implementation in the classroom was promoted by the second supportive idea: 'community of practice'. This idea was applied by designing a professional development trajectory in which several social groups met in a cooperative setting. At the school level, teachers from different departments (biology, chemistry) cooperated not only during in the meetings, but also in teaching the mini-FOI in the classroom. They functioned in small teams headed by a teacher-coordinator. At the inter-school level, teachers from different schools met each other. At the institutional level, the university coaches cooperated with the upper secondary school teachers. Such an approach is useful to all sides. Teachers cross school boundaries and get new input and feedback on their teaching approach. Coaches can implement and test their innovative ideas about supporting teachers in curriculum innovations, such as scaffolding teachers in open-inquiry teaching. Moreover, coaches get informed about teaching practices in school and how the ideas are made feasible in classroom practice. This reciprocal aspect is important to bring about co-ownership of the innovation of open-inquiry teaching (the third supportive idea). It can solve the 'agenda setting dilemma' (Richardson, 1992) as all partners contribute to the agenda of the meetings. Co-ownership of the teachers also appeared from teachers' implementation of the scaffolding tools in the classroom and their intentions to use them in their future teaching. It indicates that teachers can become co-owners of an innovation if their concerns are taken into account when the innovation is introduced into the school. With that, we are back to the scaffolding tools and their double character, which originated from the fourth supporting idea, the 'congruence principle', originally developed for student-teachers (Korthagen et al., 2001).

Synergy between the guiding principle and the supportive ideas has to be realised in concrete actions. For instance, designing teaching materials that are not offered to the teachers as ready-made products but as drafts that could be adapted to the local circumstances and to teachers' preferences, formation of innovation teams of teachers led by a team coordinator, and adapting timetables for creating space for implementing an innovation in the classroom.

These days, many innovations in science education have a socio-constructivist character. This means that the innovations should focus on active, autonomous learning and should promote communication about science among students and between students and their teacher(s). In order to realise this, professional development of teachers is needed and the learning environment, in which the professional development takes place, should also have a socio-constructivist character. We have found evidence that it is possible to implement a professional development programme for science teachers that is based on the described ideas and on the synergy between them. On the one hand, this approach needs to be put into practice in more contexts—in other schools, other countries, with other topics than open-inquiry, with students of other ages, in other sections of education (primary, tertiary). On the other hand, more research should be done in these kinds of programmes. Is it possible to get more profound learning results? In our opinion, effective curriculum innovation should go hand in hand with professional development and with cooperation within schools, between schools, and between schools and institutes for teacher education and research. Such innovations will challenge schools and teachers to participate. The scaffolding approach has to be practised by teacher educators as well in pre-service teacher education. Developing the scaffolding approach and implementing this approach in schools and teacher education institutes is the future task for the community of teacher educators, researchers, and teachers in schools.

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