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Scaffolding open inquiry: How a teacher provides students with structure and space

Abstract

The present case study examines a teacher's scaffolding strategies supporting his students during a twelve-week open inquiry project at an upper secondary school. We use interaction analysis to identify how he provides structure and space in the different phases of open inquiry as well as how it constitutes the students' inquiry process. The study reveals that the teacher scaffolded this open inquiry in two opposing ways; he created space for the students to make their own experiences and ideas, which eventually set up the need for more directed scaffolding to discuss the challenges students experienced, and directing students' ideas in certain directions in phases with structure. We suggest that the interplay between structure and space creates what can be seen as a driving force providing both exploration and direction for open inquiry. Moreover, we propose that the dual concept of 'structure and space' can work as a thinking tool to promote teachers' competence on how to scaffold more authentic versions of scientific inquiry in schools.

Introduction

Science education reforms all over the world advocate a view of learning science that emphasises inquiry (e.g. European Commission, 2007; Norwegian Ministry of Education, 2006; NRC, 2000). In the classroom, the term 'inquiry' can be understood with two different emphases: the experiments and activities that facilitate the students' learning of established sciences, and the scientific thinking and practices in which students engage when they model professional scientists (Asay & Orgill, 2010) – which is in focus in the classroom studied here. Specifically, open inquiry has been proposed as a means to enhance more authentic scientific inquiry (Duschl & Grandy, 2008; Roth, 2012) and promote active and autonomous learning (Hodson, 2009). However, change in school science depends upon how teachers conceptualise inquiry and how it is translated into classroom practice. Thus, we need to understand how the actions of the teacher influence the nature of the inquiry-based instruction and the students' learning experiences (Blanchard et al., 2010; Hmelo-Silver, Duncan and Chinn, 2007).

In this case study, we use interaction analysis to understand how an experienced upper secondary science teacher's scaffolding strategies impact the nature of an open inquiry practice and students' inquiry process. It has been proposed that in open inquiry the teacher's role change from an instruction-oriented role to a more guidance-oriented role (Crawford, 2000). An important notion concerning the teacher's role is raised by Hodson (2009) when he proposes that: 'Too much guidance can interfere with students' thought processes, act to frustrate problem solving and lead to premature closure; too little guidance can leave students unable to make satisfactory progress and lead to feelings of frustrations, and even alienation' (p. 213). Thus, there must be some kind of balance between offering the students *structure,* which scaffolds the essential features of scientific inquiry (Asay & Orgill, 2010; Windschitl, Thompson & Braaten, 2008), and *space* to develop and express their thoughts, ideas and tentative understandings (Wells, 1999). van der Valk and de Jong (2009) suggest that teachers need to know how to guide students' open inquiry projects, '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' (p. 829). The authors provide examples of several scaffolding tools, but they do not provide empirical data on how these tools were used by the teachers and what the consequences were for the students' learning process and how they were used to provide structure and space. Furthermore, they do not provide descriptions of what the term 'space' might constitute in open inquiry. Thus, more detailed descriptions from situated inquiry practices revealing how teachers combine structure and space as well as the consequences for the inquiry process are of interest. The research focus for the study, consequently, is how a teacher scaffolds the students' learning of the essential features of scientific inquiry and the development of autonomy during open inquiry.

The questions guiding this case study are:

1. What were the teacher's scaffolding strategies in the different phases of open inquiry?
2. How did the teacher's scaffolding, combining structure and space, constitute the students' inquiry process?

Theoretical framework

Open inquiry in school science as modelling professional science

Open inquiry is often described as a student-centred approach where the students are supposed to learn about the essential features of scientific inquiry through their own experiences (Asay & Orgill, 2010). According to the National Research Council (NRC, 2000), the five essential features for inquiry in school are: (a) the learner engages in scientifically oriented questions; (b) the learner gives priority to evidence in responding to questions; (c) the learner formulates explanations from evidence; (d) the learner connects explanations to scientific knowledge; and (e) the learner communicates and justifies explanations (p. 29). Open inquiry is supposed to cover all five features, and it has been suggested to replace the recipe-type of practical work in school because it is more closely related to scientific activity and reasoning (Duschl & Grandy, 2008; Roth, 2012). Moreover, open inquiry is advanced as a means to provide students with the possibility to achieve some intellectual and creative independence in taking responsibility for developing ideas and planning, executing and reporting their own inquiries (Hodson, 2009; Zion & Slezak, 2005). Open inquiry is also promoted as an opportunity for students to engage in activities to which they are committed (Hodson, 2009; Wells, 1999).

However, there are tensions between the purpose of open inquiry and the practice actually found in schools. Research reveals that open inquiry often portrays naïve versions of scientific inquiry and does not model professional science (Windschitl, 2004). For example, new technologies and new scientific theories have modified the nature of scientific observation from a practice dominated by sense perception to a theory-driven practice (Duschl, Deaák, Ellenbogen & Holton, 1999). Nevertheless, this is not always reflected in school science inquiry, where 'observations' are mostly directed by the teacher or guided by students' interests. It is seldom acknowledged as being influenced by prior knowledge, theory or models (Duschl & Grandy, 2008; Windschitl, 2004). The questions arising from students' interests are rarely informed by their understanding of a phenomenon, and this is problematic since it reinforces a naïve presumption that hypotheses are guesses about an outcome (Carey, Evans, Honda, Jay & Unger, 1989; Gyllenpalm, Wickman & Holmgren, 2010). Furthermore, the way inquiry is often presented in school as 'testing of hypotheses' following a linear process named The Scientific Method is problematic since scientific inquiry does not embody a step-by-step method based on an experimental design (Lederman & Lederman, 2012; Windschitl et al., 2008). Neither does it represent a single universal scientific method, but rather, many different approaches depending on the subfield of science (Giere, Bickle & Mauldin, 1997).

The process of open inquiry is complex, and the problems to be dealt with are ill-structured. This puts high demands on the students and the teacher. The students are supposed to achieve some sort of intellectual independence, using knowledge in creative ways for solving novel problems and building new understandings (Hodson, 2009). Therefore, the students need to learn how to fulfil a more autonomous role during the process of inquiry. Simultaneously, the teacher needs to ensure the students' understanding of the culturally and socially accepted views of what constitutes scientific inquiry (Wells, 1999). However, student-centred approaches have been accused of being unguided or minimally guided, making them less efficient than instructional approaches (Kirschner, Sweller & Clark, 2006). This critique has, among others, been encountered by Hmelo-Silver, Duncan and Chinn (2007), who have argued that successful inquiry-based learning is characterised by extensive scaffolding. However, the literature also reports teachers' lack of experience and knowledge about how to facilitate inquiry-based learning, resulting in poor learning outcomes (Asay & Orgill, 2010). This brings us to the significant role the teacher plays in supporting the students' learning from open inquiry.

The teacher's role in scaffolding students' learning during open inquiry

The scaffolding metaphor originally described a tutorial process where 'an adult or "expert" helps somebody who is less adult or less expert', including recruitment of interest in and adherence to the task (Wood, Bruner & Ross, 1976, p. 89). In a school context, scaffolding can be a teacher adjusting the complexity of a learning task so the students can engage in activities that would be beyond their unassisted efforts. The notion of scaffolding has expanded to include tools, strategies and guides to support learning processes (Sherin, Reiser & Edelson, 2004). Moreover, it changes over time, meaning that as the students gain experience with the task, support should decrease (ibid.). In a review on scaffolding of inquiry-based learning, Hmelo-Silver and her colleagues (2007) underline that an important feature of scaffolding is that it support students' learning of both *how* to do the task as well as *why* it should be done that way. The authors provide examples of three types of scaffolding strategies: to make disciplinary thinking and strategies explicit; provide expert guidance; and structure complex tasks or reduce cognitive load (p. 101). Reducing cognitive load means for example to structure a task in ways that allow students to focus on the aspects of the task that are relevant for the learning goals. The amount of information, e.g. about ways of running inquiry processes, might thus be reduced, in accordance with recommendations from cognitive load theory (Van Merrienboer & Sweller, 2005).

According to van der Valk and de Jong (2009) scaffolding students in open inquiry involves a teacher's ability to know when and how to provide students with structure and space. However, the authors do not discuss explicitly what is meant by 'structure' and 'space', respectively. Regarding the research literature on open inquiry, there seems to be agreement that the students need *structure* in the form of scaffolding tools and teacher guidance to help them organise and direct their own projects (Crawford, 2000; Hodson, 2009; van der Valk & de Jong, 2009), and to learn essential features of scientific inquiry and relevant conceptual understanding (Asay & Orgill, 2010; Windschitl et al., 2008). Moreover, it is vital for a teacher to create *space* during open inquiry for the students to follow their particular interests (Hodson, 2009; Wells, 1999) and to experience situations requiring creativity, critical thinking and reasoning skills (Hodson, 2009; Zion & Slezak, 2005).

The literature reviewed here advanced several scaffolding strategies to support the different purposes and aspects of open inquiry in school. Inspired by the literature, we have identified three main scaffolding strategies that support the research focus of the present case study. These strategies are as follows:

(1) scaffolding that makes the essential features of scientific inquiry explicit;
(2) scaffolding that structures complex tasks or reduces cognitive load; and
(3) scaffolding that facilitates phases with space for student autonomy.

Context of the study

This report is part of a larger study on a group of science teachers developing a classroom practice of open inquiry. The context is a Norwegian upper secondary school with approximately 450 students, located near the capital. It has mainly vocational education programmes, but offers a small section with programmes for general studies. The present study focus on one of the science teachers, named Amir, and his day-to-day support and interaction with his students during an open inquiry project. Amir has developed and implemented the open inquiry for ten years in his science classes. He holds a master's degree in science, and he has twelve years of experience as a science teacher. According to Amir, most students in his class were not motivated for science, and they typically displayed a shallow understanding of scientific concepts and processes. This description is consistent with our impressions during the project. Amir was sensitive to the different challenges these students presented, concerning science as a subject and other social issues. It was, without doubt, a challenging task for the teacher to create an interest in science for these students.

The open inquiry project

The open inquiry project lasted for 12 weeks, and the students spent approximately two lessons a week (45 minutes each lesson) on the project. Amir had formulated the following goals for the project: The students should learn The Scientific Method; build knowledge and stimulate their curiosity by studying a natural phenomenon; and increase their ICT competences in the natural sciences by using digital sensors in fieldwork and digital publications. In addition, the teacher formulated the goal of creating an interest in science by giving the students opportunities to be in charge of their role as natural scientists. The formal curricular goal relevant to the project was, according to Amir, 'the budding researcher', an important area in the Norwegian national science curriculum focusing on scientific inquiry (Norwegian Ministry of Education and Research, 2006). The students collaborated in groups and they got the opportunity to inquire about natural phenomena of own interest. Thus, the students' projects were very diverse, for example: Is bottled water healthier than tap water? Or, what is the connection between increased CO_2 emissions and plants' ability to produce oxygen? In the present study, we chose to follow the interaction between Amir and one of the student groups especially closely. The group consisted of three girls, Marie, Martha, and Sofie (pseudonyms). They decided to study the effect of pollution on hair quality, a phenomenon presumably close to their daily life and interests. This student group is referred to as 'the hair group'.

Methods

Our interest in how structure and space might be provided and balanced using different scaffolding strategies, made it necessary to choose a method enabling exploration over time. Thus, we chose a single-case approach (Flyvbjerg, 2011) following an open inquiry project from its beginning to its end. To be able to study interesting practices more than introductory challenges often faced by unexperienced teachers, we chose to follow an experienced teacher, Amir, who had practiced open inquiry with his students for several years. Moreover, he was outspoken and willing to share his ideas, thoughts and reflections. The study does not represents a best case; rather it provides an opportunity to explore in-depth Amir's implementation of open inquiry in a situated context, and thus increase our understanding about teachers' scaffolding of open inquiry. The point of departure for the study was the implementation of a new (at the time) natural science curriculum in Norway emphasising scientific inquiry through a main area named 'the budding researcher' (Norwegian Ministry of Education and Research, 2006). The present open inquiry project is of special interest since it represents an implementation of the aims of 'the budding researcher', which is yet not a common practice in Norwegian science classrooms.

Sources of data

The first author observed the whole class of 24 students and their science teacher from January to April 2010 during their science lessons. To get rich descriptions of the inquiry practice and data relevant for the research questions, the main focus was on interactions between the teacher and one particular student group, the 'the hair group'. This student group was selected on the following bases: it was a heterogeneous group when it came to interest in science and they had fewer absences from school than some of the other students in the class. Data included the primary sources of (a) 28 hours of video recording from the whole-class setting and the chosen student group, and (b) site documents from the open inquiry project in form of a PowerPoint presentation made by the teacher, documents at a learning platform, hands-out and students' products. The secondary sources were conversations with the teacher and students, and field notes. Data was collected during a six-month period fully covering the inquiry project studied.

Analysis

In order to answer the first research question concerning what were the teacher's scaffolding strategies in the different phases of open inquiry, the scaffolding strategies used by the teacher were first identified. The data sources were coded according to three main strategies: (1) scaffolding that makes the essential features of scientific inquiry explicit; (2) scaffolding that structures complex tasks or reduces cognitive load; and (3) scaffolding that facilitates phases with space for student autonomy. The first two are based on the above-mentioned categorisation by Hmelo-Silver and colleagues (2007). Category 3 was included as scaffolding of more open phases seems missing in the authors' categorisation, but of special relevance for our study. Following the identification of scaffolding strategies, a thematic analysis was done through clustering of codes from the data material to provide a framework of the teacher's scaffolding strategies in the four main phases of the project (table 1).

The second research question about how the teacher's scaffolding, combining structure and space, constituted the students' inquiry process, was answered using interaction analysis to enable the formulation of emerging issues (Jordan & Henderson, 1995). The analysis was inspired by Högström, Ottander and Benckert (2010) and their interaction analysis of practical work. The analysis started by inspecting the material and identifying how teacher-student and student-student interactions were structured, and what made the participants act the way they did. It was an iterative process of discussing preliminary findings within a group of researchers familiar with the context, and reviewing the video recordings and site documents to identify issues appearing to be of importance (Erickson, 2012). The emerging issues were found by identifying: short versus long discussions, words and concepts that were continuously repeated, expressed frustrations or excitement. Issues emerging across instances were identified as robust (Jordan & Henderson, 1995). Moreover, these emerging issues were transcribed, representing the participants' talk, object manipulation, document processing and employment of PC and data-loggers, and aspects of the students' body language, such as excitement or boredom. The emerging issues were viewed in relation to the teacher's scaffolding strategies and how it provided the students with *structure* and/or *space* – for example; how the teacher directed the students' ideas in a certain direction by asking questions (structure), or how he motivated them to follow their own ideas (space), and furthermore the consequences of these strategies for the participants' interactions.

Results

The findings of this study are organised around the research questions, beginning with the teacher's scaffolding strategies in different phases of the open inquiry (table 1). The second part shows the result of the interaction analysis, revealing two main emerging issues concerning how the teacher's alternation between providing *structure* and *space* constituted the students' inquiry process.

Table 1. The teacher's scaffolding strategies providing structure (1 and 2) and space (3) in the different phases of the inquiry project. The scaffolding strategies consisted of a mix of verbal guidance, peer-discussions, structured inscriptions and physical equipment (data loggers). The teacher's strategic use of these 'tools' and the dynamic shifts between providing structure and space is analysed in the following sections based on the two most prominent emerging issues identified.

Phase of the inquiry project	**Introduction (2 hours)**	**Design and planning (4 hours)**	**Performance and reflection (10 hours)**	**Presentation (3 hours)**
Activities	Introduction by the teacher to the project and The Scientific Method	Students worked with ideas and formulated the research question, hypotheses and a research design	Students did experiments and collected data, and they discussed the results	Students presented their results in the form of a poster, and they handed in a written report
(1) Scaffolding that makes the essential features of scientific inquiry explicit	Modelling The Scientific Method using a simple example about worms. Asking questions and providing cues Providing examples from previous student projects	Verbally guiding the individual student groups concerning ideas and measuring methods Research meeting 1*	Verbally guiding the student groups concerning procedural issues Data loggers and software to collect and record data as well as make graphs and tables Research meeting 2*	Verbally guiding the students' groups Poster session
(2) Scaffolding that structures complex tasks or reduces cognitive load	PowerPoint presenting The Scientific Method as a step-by-step method Show posters from previous projects	Whole-class instructions to guide the students' progress: as a road sign Learning platform containing: • template for the tasks following The Scientific Method • template for log • room for feedback from the teacher • links to literature • timetable • assessment criteria	Whole-class instructions guiding the students' progress: as a road sign Learning platform resources (same scaffolds as in the planning phase).	Whole-class instructions guiding the students concerning the poster exhibition Template for the posters Posters from previous years' projects

table cont.

Table 1 cont.

Phase of the inquiry project	Introduction (2 hours)	Design and planning (4 hours)	Performance and reflection (10 hours)	Presentation (3 hours)
(3) Scaffolding phases with space for student autonomy	Intriguing examples for recruitment to the project Legitimise creativity and independence	Learning platform resources Research meeting 1 Questions that open up students' ideas and thought processes Encourage creative solutions	Learning platform resources Research meeting 2 Questions that open up students' ideas and thought processes Encourage independence	Template for poster Encourage creative solutions regarding the poster exhibition

**Research meetings 1 and 2 modelled professional science in the way that the students were supposed to present ideas and preliminary findings for each other, and receive and provide feedback.*

Identifying how the teacher's scaffolding constituted the students' inquiry

Two main emerging issues were identified through interaction analysis, revealing how the teacher alternated between providing the students with *structure* and *space* and how it constituted their inquiry process. The analyses of the emerging issues are presented according to the timeline of the project.

Using The Scientific Method to structure open inquiry and create space for ideas

The first emerging issue was found in the introduction and planning phases; the teacher continuously repeated The Scientific Method both to describe scientific inquiry and as a step-by-step method scaffolding the inquiry project. In addition, he focused, with enthusiastic verbal guidance, on the possibilities open inquiry provided the students to explore a natural phenomenon in which they were interested. The emerging issue is illustrated by the following examples that emerged across situations.

Amir introduced the project by presenting learning goals and the relevant formal curriculum to structure and narrow down the focus of the open inquiry. Moreover, he used a PowerPoint with pictures, texts and drawings to explain the so-called steps of The Scientific Method. Interactions were directed by Amir, using cues and asking simple questions in a whole-class setting. Figure 1 represents the teacher's PowerPoint slide summing up the inquiry process for the students.

The following words from Amir guiding his students emphasise his concern: 'Whether it be four steps or a hundred, this is the essence [of The Scientific Method]'. This four-step structure not only gave students an overview that was possible for them to remember and motivated them by making the process seem manageable, but it also narrowed the students' tasks by making some activities seem relevant and others irrelevant in different phases of the project. Thus, it put restrictions on the students' activities and provided a focus for their thinking, indicating that there was no 'space' for going outside these borders.

Furthermore, Amir presented a site at the learning platform to scaffold the project, including a template for the inquiry process, a timetable and the assessment criteria. The content of the template is given in Table 2.

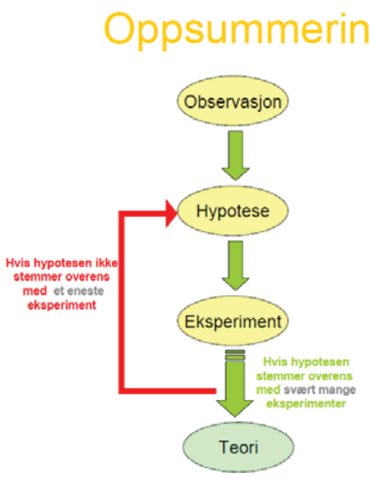

Figure 1. The teacher's representation of four main steps in The Scientific Method ('Observation → Hypothesis → Experiment → Theory'. Red arrow: 'If the hypothesis is not consistent with a single experiment').

Table 2. The template at the learning platform used to scaffold the students' inquiry projects.

Theme/problem	Write a short and precise title that shows what you are doing research on.
Observation/background	What have you observed, learned, or know about the phenomenon you want to study? Why did you choose your theme?
Hypothesis	A well-thought-through guess/assertion you state is the main cause of the phenomenon.
Experiment	What are the experiments you want to perform to find out if your hypothesis is valid?
This week's log	Write at least, once a week, a short but precise report about what you have done/what has happened regarding the research problem. Important: each group member should choose her own colour for the text when writing a log or other things.
Literature/relevant theory	Here you can write/cut and paste theory you read/find during the process.
Questions	Here you can ask questions to me or other supervisors (professional problems and other practical things that concern your problem).
Comments from the teacher	Here there will be comments when necessary from all the students in the class and the teachers.

The students were supposed to fill in the template during the inquiry, and the teacher provided feedback directly into the table. Thus, it worked as a guide for the students, focusing the students' work into presumably achievable pieces. Moreover, the template included the main steps of The Scientific Method (Figure 1). In that sense, Amir used The Scientific Method both as a *descriptive account of scientific inquiry* and as a *method for scaffolding* the students' inquiry projects, possibly reinforcing the image of scientific inquiry as a step-by-step procedure to follow. Moreover, theory was presented as a separate entity and not as an integrative part of the inquiry process. The following excerpt reveals what the hair group wrote in their template about the observation/background for their inquiry project.

> *We are concerned about hair and how it looks, that it's healthy and fresh and how we style it. (…) We did not know anything in particular about research on hair previously, but we thought this could be interesting. It took some time before we found out just what we would like to discover about hair. Finally, we decided that we wanted to investigate if smoking over time damages your hair. There are many kids who smoke today, and they are very concerned about their hair, so we thought it would be interesting to investigate this.*

The students chose a phenomenon that was close to their daily life and intriguing for them to explore. Amir created a space for the students to use their creativity to develop own ideas within the framework of The Scientific Method, thus facilitating the students' thinking about researchable problems. The following excerpt illustrates how Amir used verbal guidance in the planning phase to encourage the students to follow their interests.

> Amir: *Did you come any further with your research problem and hypotheses?*
> Sofie: *We've found some things…the research problem is pollution of hair, and we've found some subcategories like cigarette smoke, street pollution, bonfires, dirty hair, clean hair …*
> Amir: *Mm, yes. Actually, it is fascinating; I find every case exciting to look at. This is the first and last opportunity you have in upper secondary school to do something from scratch, so I hope and expect that you'll participate fully. (…). Throw yourself wholeheartedly into the problem. I think you'll get many good findings.*

The excerpt reveals that Amir's concern was to provide encouraging feedback to the students' ideas, enlisting the students' interest in and adherence to the project. Thus, he was creating space by legitimising creativity and independence within the frames of The Scientific Method.

In sum, during the phases of introduction and planning, Amir chose to focus on The Scientific Method as descriptive account of scientific inquiry as well as a scaffolding strategy in the form of a template framing the students' work and dialogues. The students were asked to follow and fill out the template, providing structure for the inquiry process and simultaneously allowing space to introduce their own ideas within the constraints of the structuring template. Thus, the duplicity of the template somewhat meets the tension between Amir's concern of opening up for students' interests and thought processes relating to a natural phenomenon and his awareness of the need to provide structure to enable students to fulfil the inquiry and develop certain insights. Thus, having narrowed the students' freedom through the demands of the template and the model of the scientific inquiry, the teacher could provide space for students' ideas while still keeping the work relevant for the identified learning goals.

Providing space to experience the complexity of inquiry and readiness for guidance

The second emerging issue was found in the performance and reflection phase, when the students worked independently in groups, collecting data and struggling to make sense of it; they experienced that The Scientific Method was more complex than they first anticipated from the teacher's initial guidance. Moreover, the analysis reveals that the experiences made in periods of space were important for the students' readiness for guidance through scaffolding structures like 'research meeting 2' and the poster session.

During the performance phase, interactions between the teacher and the students changed in character towards real-time guidance, which was less frequent. The teacher encouraged the students to solve the tasks within the group, and student-student interactions were dominant. The hair group enjoyed using the equipment available at the school lab to test hair samples, measuring hair strength with a digital force meter, hair thickness with a digital calliper, the amount of 'pollution' on the hair using a turbidity meter, and a microscope to observe hair structure. However, the lack of proper research design made them explore several parameters without clear purpose, and their progress was slow. Nevertheless, the space did provide the students with some valuable experiences concerning the process of inquiry. The following excerpt illustrates how the hair group discovered an important methodological limitation that helped them to reduce the amount of hypotheses, control variables and finally make a design:

> Sofie: *If we are going to include smokers, how are we going to study that? I think that, if we're looking at Nina's hair [smoker], I don't believe it will be more polluted than … it has to be damaged in some [other] way. We can look for thickness, but then of course, people's hair has different thickness from the start. We can check strength, but anyway, people's hair can have different strengths [from the start]. It will be totally uninteresting since we won't know if it's the result of smoking. But, what we can do is take samples from many people.*
> Marie: *You can smoke a cigarette in front of a person that doesn't smoke.*
> Sofie: *But, do you know what we can do? … take a hair sample from someone that has never smoked and hair from several smokers and see if there's a correlation.*
> Martha: *Yeah, we need to have more … [samples]*
> Marie: *Yeah, we need to cut down on the number of other hypotheses.*
> Sofie: *Then it will only be smokers or no smokers. … okay, we must reconsider the whole thing.*

The excerpt reveals how the students were able to solve emerging problems together to find a research design that could take into account people's different hair quality.

In the phase of performance and reflection, the students' talk was largely about procedures and fair testing. The scaffolding structure 'research meeting 2' was implemented for the students to present their preliminary findings and suggest how their data could be interpreted to answer their research question, and to get feedback on their work. The following excerpt from the research meeting illustrates how the hair group presented their findings.

> Martha: *We haven't compared the results with any data yet.*
> Sofie: *Theory …*
> Martha: *Or something, we have not …*
> Sofie: *We've found some theory that makes us believe that there is a connection between hair and whether you smoke or not. Then, there are the sources of error like the equipment (…) and if we have enough hair samples to actually see a connection, because all people have different hair thicknesses and so on (…). I think there is a correlation between smokers and their hair, but I'm not sure if we'll be able to see this, because there are too many discrepancies and errors.*

The students were able to reflect on important procedural issues that they had experienced themselves through the inquiry process. In 'research meeting 2', the peers were supposed to act as 'critical friends'. In this case, their questions were about measuring uncertainties, thus reinforcing the focus on procedural issues.

In the lesson prior to the poster exhibition, the hair group was still collecting data. The deadline to finish the experiments conflicted with the time necessary to discuss data. This was contrary to the teacher's intentions as expressed in the assessment criteria and his introduction to 'research meeting 2', focusing more on understanding data within a theoretical framework. At the poster exhibition, Amir had arranged for external judges to assess the projects and select the winners of three prizes. The following excerpt is from a conversation between the hair group and Petter (judge), revealing how Martha reflected on the limitations of their study and what she had learned from it.

Petter: *So, there are other variables that interfere with the variables you were looking for. How many samples were needed then, do you think?*
Martha: *Eh, we should probably have had up to a hundred for each of them ... to see ... we should at least have much more than the four we had. And we should have been much more careful so the people we took hair samples from washed their hair with the same shampoo and did it just before they gave us the hair samples and gave us information if they coloured it or used a hair straightener.*
Petter: *Okay, so you could have planned in more detail the tests you did. (...) It seems that you have learned a lot about how difficult it can be to measure such things.*
Martha: *Yeah, that's probably what we have learned the most of, how much you need to know and how hard it is to come up with concrete things.*

The students were able to reflect critically on what went wrong and what they could have done differently concerning important procedural issues. Moreover, the hair group's own experiences provided a foundation for guided reflections with the judge regarding procedural issues of inquiry. They also presented some theory for the judge about how smoking cigarettes affects hair, but they did not connect it to their own results, claiming it was difficult to read anything out of their samples.

In sum, in the phase of performance and reflection, the teacher provided space for the students to make their own experiences. He used these first-hand experiences as a valuable point of departure for structured guidance to support and make explicit important procedural issues of scientific inquiry. This guidance narrowed the possible ways of interpreting and handling the problems experienced. It was followed by a phase with space in which students tried to take advantage of comments in the structured phase. Interestingly, this implies that, in order to provide experiences facilitating students' interest and understanding during structured guidance, the phases of *structure* were preceded with *space*. Less surprising, the phases with *space* were followed by *structure* in order to support the inquiry processes. Thus, in this case, *structure* and *space* both work as means to an end. Moreover, both works as ends; *structure* for clarifying ideas and scientific processes; *space* for training the application of ideas and autonomous practice of scientific inquiry.

The students' actions and reflections show that they perceived 'doing' the experiment and finding patterns in observations as most salient: theory was more or less pasted into the poster and the report without linking it to the experimental part. This conflicted with Amir's purpose of scaffolding structures like 'research meeting 2' and assessment criteria supporting the implementation of theory. However, it can be explained by the scaffolding in the introduction and planning phases, putting weight on The Scientific Method through the PowerPoint presentation and the template at the learning platform, where theory was handled as a separate entity. The phase of planning did not contain guidance and constraints (e.g., task or template) indicating a need to enter problems and experiences where theory probably would become an issue. The students were therefor probably not prepared to prioritise and take advantage of structured scaffolding related to the inclusion of theory later in the inquiry process. Thus, a fruitful switching between space and structure did not occur in this situation where experiences in a phase with space did not trigger a need for structured guidance, indicating that space and structure have to interact fruitfully with aims of a project as understood by the students.

Discussion and implications

The findings from the present study broaden our understanding of how a teacher's scaffolding strategies, providing students with structure and space, has consequences for students' inquiry process.

We found that Amir used the four-step version of The Scientific Method both as a *descriptive account of scientific inquiry* and as a *method for scaffolding* the students' inquiry projects. Taking into consideration that one of the goals of the project was students' learning *about* scientific inquiry, the teacher's combined use of The Scientific Method might be viewed as problematic. It might lead towards an understanding of scientific inquiry as a simplified method built on the narrow epistemology associated with The Scientific Method (Windschitl et al., 2008). However, in addition to using the four-step version to *structure* students' work and thinking, Amir provided *space* for the students to experience the complexity of scientific inquiry themselves and thereby possibly counteract some of the simplifications.

The hair group was able to work independently through periods of space within the framework of The Scientific Method. The autonomy role (Hodson, 2009; Wells, 1999) was clearly driven by the students' interest in and ownership of the phenomenon, and it was encouraged by the teacher throughout the inquiry. The initial structuring of the steps of The Scientific Method created constraints for students' subsequent problem solving. When the students performed their own inquiry struggling with procedural issues, they used skills like creativity and critical thinking (Hodson, 2009; Zion & Slezak, 2005) to solve emerging problems together. Moreover, these partly challenging experiences during periods of space were followed up by structure, where the students' reflections were guided. Periods of productive space were characterised by the students' experiencing some of the complexity of the inquiry process, allowing them to express their thoughts, ideas and tentative understanding (Wells, 1999). Moreover, these complex experiences provided an important impetus for meaningful scaffolding through periods of structure. Thus, the alternation between structure and space was valuable supporting the students' inquiry process, especially concerning procedural issues of scientific inquiry.

However, the dynamic alternation between structure and space was less pronounced when it came to the role of theory in formulating scientifically oriented questions and discussing one's own data (NRC, 2000). The simplified step-by-step method and the template implemented in the phase of planning presented theory as a separate entity, not as something useful for the inquiry process. Moreover, Amir provided enthusiastic feedback to students' ideas, but without guiding them towards more scientifically oriented questions. The teacher's lack of focus on relevant theory can be interpreted as a strategy for reducing complexity and cognitive load for the students (Van Merrienboer & Sweller, 2005). This scaffolding had consequences; the students did not make experiences related to how theory could inform their ideas. Later in the project, during the phase of performance and reflection, the implementation of scaffolding tools like assessment criteria and 'research meeting 2' focused on the interplay between students' own data and relevant theory. However, since the students had not experienced situations where they needed to focus on theory before this stage, the scaffolding tools did not support their inquiry as intended. This interpretation is supported by the fact that in their written products, in form of poster and report, theory was presented as a separate entity.

Considering the amount of science education literature revealing that 'hands-on' activities are often not 'minds-on' activities (e.g. Asay & Orgill, 2010; Roth, 2012; Tiberghien, Veillard, Le Maréchal, Buty & Millar, 2001), addressing how different scaffolding strategies constitute the students inquiry process becomes an important issue. The present case reveals that scaffolding, in the form of tools and verbal guidance, were used for different purposes throughout the open inquiry. In specific, the case shows how shifts between scaffolds providing structure and space can facilitate both clarification of ideas and experiences of complexity and autonomy. However, the study also exemplifies the need for scaffolding structures having an explicit focus on relevant scientific content and clearly supporting students' understanding of *how* and *why* theory informs scientific inquiry (Hmelo-Silver, Duncan and Chinn, 2007; Windschitl et al., 2008).

Importantly, the presented case indicates (1) that challenges students have experienced in open phases can lead to student interest for guided reflections in structured phases and (2) that structured phases might involve guidance and constraints, leading students to experience autonomy without being perplexed by complexities, and make experiences relevant for further guidance. Scaffolding normally involves less support as the students gain experience; however, new features of scientific inquiry emerge along the whole process, demanding subsequent support.

Implications

We believe that the dual concept of 'structure and space' (van der Valk & de Jong, 2009) is valuable to promote teachers' competence on how to scaffold open inquiry. Our analysis shows that open phases could provide complex experiences relevant for subsequent structuring, and phases of structure could provide ideas and direction preparing students for more autonomous phases. This analysis is consistent with theories on how experiences might provide basis for structured reflection (Abd-El-Khalick, 2012) and how ideas discussed needs to be applied and explored to advance deep understanding (Bransford, Brown, & Cocking, 2000). This analysis also provides a possible answer to the challenge articulated by several researchers (Hodson 2009; van der Valk and de Jong 2009) on how scaffolding tools and guidance can be combined and balanced in a way that supports students' learning and autonomous practice. We suggest that there exist a necessary tension and interplay between structure and space, creating what can be seen as a driving force providing structure, content and direction for the students' own experiences from open inquiry.

Figure 2 provides a visual model of our thinking of how structure and space might alternate in a mutual supportive way, leading to continued progress within a competence in focus. The model is suggested as a 'tool' for teachers' and student teachers' planning and reflection on how to combine structure and space to scaffold open inquiry to support essential features of scientific inquiry.

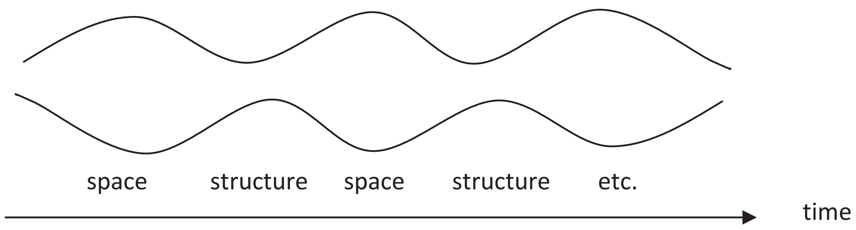

Figure 2. A visual model of how the process of open inquiry might be scaffolded by alternating between structure and space, and where both type of phases feeds into the following phase.

The model reveals how periods of space are both preceded and followed up by structure to support essential features of scientific inquiry. For example, when the purpose is for the students to work creatively, developing their own ideas, the teacher might choose to plan for explicit support (*structure*) in advance, appropriate for the students so they can work autonomously, developing researchable ideas. In this case, the teacher could provide scaffolding (e.g., read relevant literature, ask experts, detect relevant parameters) that enables the students to make their own challenging experiences (*space*), trying to understand how it can inform their research design. The following structured phase (e.g., teacher guidance approving students' ideas) then attracts students' interest when it focus on challenges the students have experienced in periods of space. In addition, structured guidance is necessary to help the students reflect on their experiences and develop an explicit understanding of the epistemological dimensions that support their inquiries.

This dynamic model of 'structure and space' might help increase the synergy between what Abd-El-Khalick (2012) calls the 'lived' (doing) and 'reflective' perspectives of scientific inquiry, providing more robust inquiry learning environments. Moreover, the 'thinking tool' can become valuable in supporting teachers' (students) collaboration to improve science inquiry. The tool can help facilitate the exploration and negotiation (Engeström, 2001) of how to scaffold the students' inquiry process depending on the learning goals – providing both 'structure and space'. The use of diagrams/tools also allows the teachers to slow down the pace (Furberg, Kluge, & Ludvigsen, 2013) and spend considerable time on planning, which is vital to create more robust versions of open inquiry.

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