Strategies to Scaffold Students' Inquiry Learning in Science

Morten Rask Petersen*

Department of Applied Research in Education and Social Science, UCL University College, Odense, Denmark

*Corresponding Author: mrpe@ucl.dk

ABSTRACT

Inquiry-based science education (IBSE) has made a massive entry in science education classes. Students work with their competence development through inquiry. Such an approach calls for new strategies from the teachers to help students learn through inquiry. This study takes a descriptive approach to teachers' understanding and usage of such strategies. Through classroom observations, video analysis, and teacher interviews, three cases are identified to hold teacher practice against a theoretical framework on scaffolding strategies where focus is on the means and intentions of scaffolding. The findings show that teachers use different scaffolding strategies according to the students' level of inquiry understanding, and that scaffolding takes place in short sequences, but the findings also show that the teachers themselves are not aware of such differentiated usage of strategies. This calls for a both better understanding of teachers' usage of scaffolding strategies and for professional development in being aware of how to use such strategies for best practice with students.

KEY WORDS: Inquiry learning; scaffolding strategies; scaffolding intentions; student responsibility

INTRODUCTION

When talking about students doing experiments Hodson (2014) distinguishes among: (1) Learning science, (2) learning about science, (3) doing science, and (4) addressing socioscientific issues. This study focuses on the interaction between learning science and doing science. One does not necessarily exclude the other, but it is possible to learn science without doing it and vice versa. Learning science is "acquiring and developing conceptual and theoretical knowledge," and doing science is "engaging in and developing expertise in scientific inquiry and problem-solving" (Hodson, 2014, p. 2537). Conventionally, to learn to do experiments in school has been like following a recipe and reproduce standard experiments correctly (Lunetta et al., 2007) and is thereby seen as learning science This has been challenged by doing science in the inquiry-based science education (IBSE) approach. IBSE is a combination of doing science with the purpose of learning science in that students' acquire knowledge of the concepts they are inquiring. The main idea of IBSE is to emphasize students' active learning, constructivist teaching, self-discoveries, questioning, motivation, and peer collaboration (Anderson, 2002; Areepattamannil, 2012; Harlen, 2013; Minner et al., 2010). When students inquire using their own questions, they get more involved, engaged, and perceive a relevance of their work. At the same time, much of this work is only doable in groups and thereby challenging students both in questioning, peer collaboration, and argumentation. The main focus in students' learning in an IBSE setting thereby shifts from content knowledge toward competence development and from learning science toward doing science. For such reasons, IBSE has gained increased popularity in the last couple of decades in

Europe (European Commission [EC], 2007) and has appeared in many large research and development projects funded by EU with IBSE as a central turning point (e.g., ESTABLISH, Pollen, Fibonacci, PATHWAY, SAILS, PROFILES, and ASSIST-ME).

Changing such a tradition also calls for a change in assessment and in the teacher's role (Rönnebeck et al., 2018). Instead of direct instruction, the teacher's role shifts toward more scaffolding and supervision of the students' learning. To do so teachers need to be aware of the very essence of IBSE (Lotter et al., 2007), but since this cannot be said to be just one method, the essence can be hard to grasp. Often, research articles on IBSE make a reference to the United States' The National Science Education Standards (Leonard et al., 2009) where inquiry is defined as a list of competencies such as: (i) questioning, (ii) doing observations, (iii) testing explanations, (iv) peer collaboration, (v) critical thinking, and others.

In practice, many teachers expected to do inquiry-based science teaching do not have the experience with this approach or may have underdeveloped understandings of the concepts, which makes the assessment in students' inquiry learning even harder for the teachers (Blanchard et al., 2009; Ireland et al., 2014). In this study, the aim was to investigate teachers' scaffolding interactions with students during inquiry learning. The focus in this study was on the differences in teacher scaffolding strategies according to the students' level of self-guidance in the inquiry setting. The research question to pursue this was:

How does teachers' scaffolding of students differentiate according to the students' capability of doing inquiry processes?

First, there is an introduction to the concept of scaffolding and how it is used in this investigation. Next, two cases

are presented, in which teachers are doing inquiry teaching including scaffolding of their students during the process. Finally, the result of the analysis of these cases is presented and the findings are discussed.

BACKGROUND

The metaphor of scaffolding is usually contributed to Wood et al. (1976) who used it to explain different strategies in tutoring of infants. The concept has a near resemblance to the metaphor of a "construction zone" as a view on learning originally suggested by Lev Vygotsky (Newman et al., 1989; Vygotsky, 1978). Much research has since used and extended the metaphor of scaffolding as a way to explain the connection between instruction and learning on different educational levels and in different subject domains (Belland et al., 2013; Puntambekar and Hubscher, 2005; Sherin et al., 2004; Stone, 1998). This is also the case in research in science education (e.g., Belland, 2017; Kawalkar and Vijapurkar, 2013; Lin et al., 2012). Recently, Van de Pol et al. (2010) developed a conceptual model of scaffolding based on a review and synthesis of research on the topic. This model was originally used to show the development in teacher-student interaction over time (Figure 1).

This model operates with some basic distinctions and relations such as: (i) Timeline, (ii) contingency, and (iii) assessment strategies and scaffolding strategies.

Any activity follows a timeline. The model does not specify the time interval between Time 1 and Time 2. The transfer of responsibility is context dependent or contingent. The temporality of learning raises in itself a question: How long will it take for the scaffolding to show some effect in the student learning outcome? How quickly does an individual student will learn a particular science content (e.g., a special kind of procedural knowledge in the act of experimenting) is dependent both on the scaffolding strategies which the teacher decides to use and the complexities of the single student (like

Figure 1: A conceptual model of scaffolding (from Van de Pol et al., 2010, p. 274)

his or her personal background, prior knowledge, motivation, etc.). Both will have an impact on how fast the transfer of responsibility will go.

In the interactive process between teacher and students, there is a contingency, that, according to Van de Pol et al. (2010) is to be understood in the following way:

> … as responsiveness, tailored, adjusted, differentiated, titrated, or calibrated support. The teacher's support must be adapted to the current level of the student's performance and should either be at the same or a slightly higher level. A teacher acts contingently when he/she adapts the support in one way or another to a (group of) student(s). A tool for contingency is diagnostic strategies. To provide contingent support, that is, one must first determine the student's current level of competence. Only with such knowledge can the support to be provided be adapted to the student's level of learning (i.e., made contingent). (p. 274f)

In this way, the role of the teacher is to be supportive in the learning process and to balance this support in the knowledge of the progressions the student makes. It is important for the teacher to find out if the student can work independently with a task and to enhance self-regulated learning. This is in the model described as the responsibility of the student, but it must be noticed that it is the responsibility of the teacher to be able to judge how much responsibility for learning the student can carry.

The teacher's diagnostic strategies are based on responses from the student and conceptualized as the fading of support and the transfer of responsibility. After assessing the students' knowledge, the teacher can make use of the different scaffolding means to further support students' learning and drive them toward more responsibility. Van de Pol et al. (2010) identified six different scaffolding means: (i) Feeding back (referring back to students' thoughts or work), (ii) hints (clues to help students go forward), (iii) instructing (telling students what to do), (iv) Explaining (giving scientific explanations for students' work), (v) modeling (providing perceptions or models that can put students' work in perspective), and (vi) questioning (diagnosing students' work). How these can work depends on the context and the learning diagnosis done by the teacher (Belland et al., 2013). The timing of the scaffolding – when to give hints and when to instruct – is one of the decisions teachers are facing in the "rough and tumble of practice" (Crawford, 2007, p. 613) and it is the purpose of this study to dive into how, when, and why given means are used in the scaffolding process.

In relation to the scaffolding strategies Van de Pol et al. (2010) argue the importance of distinguishing between scaffolding means and scaffolding intentions, and that the combination of these two form a strategy. Intentions can be the support of students': (i) Cognitive activities, (ii) metacognitive activities, or (iii) student affect.

In this study, the framework of Van de Pol et al. (2010) was used to look only at relatively short moments not longitudinal
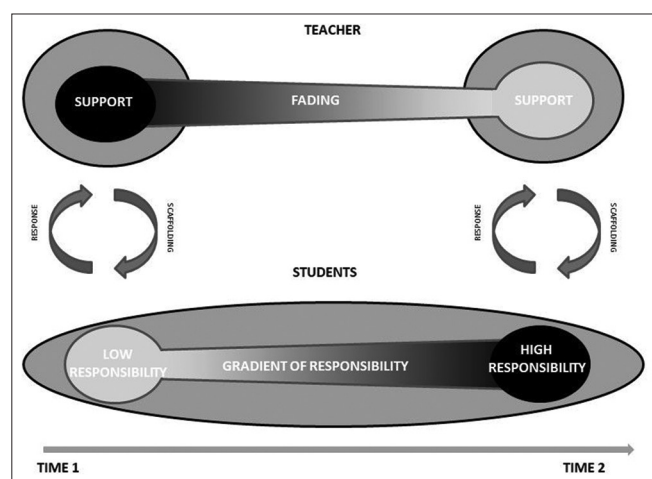
part of the cases. The focus is on student groups with different levels of inquiry competencies and student responsibility.

THE CASE STUDY

This article presents a case study on student-teacher interaction during inquiry-based science education. Three cases are presented that deliver the empirical data from inquiry lessons in Danish lower secondary schools (students aged 14–16). All students and parents handed in a declaration of consent to participate in the study.

Case Study Design

Case study as a research method does not have one specific way to be carried out. Different methodologists argue for using case studies in a range from strict frameworks to more explorative and open approaches during the research process (e.g., Yazan, 2015). This study's case study is grounded in the constructivist approach inspired by Merriam (1998) who defined a case study as particularistic, descriptive, and heuristic. This case study was particularistic in that there was a focus on student-teacher interactions in the classroom. The study was descriptive in the unfolding of scaffolding means and intentions in these interactions, and also heuristic in opening up a field for development of both research and practice.

Research Setting

A session on ultraviolet (UV) radiation was adapted from Kristianstad University for use in the EU FP7 SAILS project on assessment of inquiry skills. The session on UV radiation was intended as an inspiration to how teachers could introduce the topic of UV radiation in science classes with an inquiry approach. The session proposes a three-level approach where the students should (i) detect indicators of UV radiation and the characteristics of these indicators, (ii) detect sources and maybe intensity of UV radiation sources, and (iii) develop and test ideas on how to reduce exposure to UV radiation. Besides, the actual planning of the session opportunities for assessment of students learning through the inquiry process were also provided. In this particular session, the teachers were provided with a rubric addressing different inquiry skills from which to choose their focus. To assess the students through the use of rubrics the teachers needed to address the students with questions not only to determine the current level of understanding but also to help the students in their further development of deeper understanding and expansion of their skills and competencies (Jonsson and Svingby, 2007).

Two teachers from two different schools tried out the teaching design on UV radiation in lower secondary science education. Each session on UV radiation lasted 90 min. In the practical application of the unit, two teachers using the unit in three different classes were examined. Teacher 1 worked at an independent boarding school for lower secondary students and used the design in two different classes. She had a combination of Grade 9 and Grade 10 students (students aged 15–16) who all took a voluntary course in science. In the first class, there were 19 students while there were 13 in the second. The teaching in both classes followed the three steps of the original unit. The teacher started out with a search for students' prior knowledge gathering information with a common brainstorm on the topic of UV radiation. After this, all groups (five in Class 1 and four in Class 2) had 10 min to search on the internet for their upcoming investigative question. The search was followed by an update of their mapping from the brainstorm. Next, the students were introduced to different materials for usage such as white paper, tonic water, and UV beads. The students then investigated these different UV indicators through their own design of experiments. After this, the students posed new investigative questions on how and where to detect sources of UV radiation, on which the students designed and conducted an investigation on how to prevent exposure of UV radiation. Finally, the groups presented their investigations and results to other groups and there was a peer discussion on both design and results from each group.

Teacher 2 conducted a similar approach to his teaching of a 9th grade class with 20 students (students aged 14–15). Instead of having the students seeking their own information through web sources, he introduced some content specific knowledge to the students by letting them watch a video on UV radiation. After the introduction, the students were to do the same three-level approach as Teacher 1 and as proposed in the session. As a further indicator for detecting UV radiation, the teacher had bought fluorescent markers for highlighting written text. The students were to get the ink out of these markers for further usage. This seemed like a good motivational starter because the students liked the different colors from the markers when induced with UV radiation in an otherwise dark room. A small difference between the settings between the two teachers was that Teacher 1 had the groups work in their own pace with the three steps in the lesson. This meant that some students still could be working with step one, while others were off to step two or three. Teacher 2, on the other hand, ended each step with a sum up for the whole class when going from one step to another.

Data Collection and Analysis

The data were collected as qualitative data to enhance the explorative and heuristic approach of the study.

Classroom room video recordings

To determine scaffolding means, the lessons were video recorded. The recordings of the inquiry were not planned to specific groups but followed the teacher to capture the student-teacher interactions. From these recordings and the classroom observations, during recording, three groups were chosen for further analysis. The three groups each represents cases along the span from the theoretical framework of Van de Pol et al. (2010) where Case 1 represent students capable of doing the inquiry process, Case 2 represents students capable of doing the inquiry process with some help, and Case 3 represents students not capable of doing the inquiry process even if helped.

Student-teacher interactions from the video recordings were transcribed and analyzed for scaffolding means through directed qualitative content analysis (Hsieh and Shannon, 2005).

Teacher interviews

To determine the intentions of the scaffolding, the two teachers were interviewed 6–10 days after carrying out their inquiry teaching. These interviews followed an interview guide for a semi-structured interview (Kvale and Brinkmann, 2009). The interviews were focusing on the teachers' strategies for scaffolding and assessing students in their competence development. Each interview lasted for approximately 45 min. The interviews were recorded on video, transcribed, and analyzed through both conventional and directed qualitative content analysis (Hsieh and Shannon, 2005).

FINDINGS

The findings of this study appear in two different parts. First, the analysis of scaffolding means found in the video recordings of classroom observations is presented and then a presentation of the analysis of scaffolding intentions found in the teacher interviews.

Analysis of Scaffolding Means

The descriptive analysis of scaffolding means showed that the teachers scaffolding strategies differed according to the students' ability to self-guidance and knowledge on experimental methodology. This is shown through excerpts from each of the three cases. The excerpts highlight the differences in the fading of support and transfer of responsibility of learning between the cases. They also give an insight into some of the scaffolding strategies the teachers used. Each of the excerpts is marked in the scaffolding model (Figure 2) as an example of different steps in a learning progression. The excerpts specify the scaffolding means used by the teachers by marking each mean with [F] (Feeding back), [H] (Hints), [I] (Instruction), [E] (Explaining), [M] (Modelling), or [Q] (Questioning). These markings expose the pattern of scaffolding means used by the teacher in each excerpt to form a strategy.
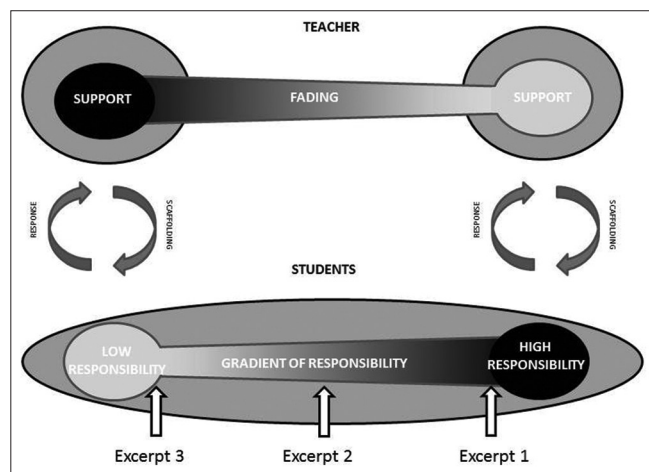

Figure 2: The three excerpts placed along the gradient of student responsibility

Case 1 is a group of students working in the third level of the UV investigations. The group has set up an experiment for reducing UV radiation with clothes. During the exercise, this group worked mainly without help from the teacher.

Excerpt 1 (teacher-student interaction – Teacher 1):
Teacher (T): It was the one with clothes, right?
Student (S): Yes
T: Ok
S: Here, we have a dish and we have some clothes and we take it into the sun for 40 s and then take them in again and make them white. And then we could try it on more layers of clothes.
[Q] T: So, it is these particular clothes every time?
S: Yes
[Q] T: But it is one layer, two layers, and three layers?
S: Yes
[Q] T: OK. And 40 s?
S: Yes
[Q] T: OK. And how do you then judge?
S: We thought of taking a picture of them [UV beads] after the first layer
T: Ok
S: And then we can make judgments from this.
[Q] T: Yes … (longer break)… Do they get the same colour?
S: The beads?
T: Yes
S: No
[Q] T: Do they change in the same rate?
S: I don't know but it doesn't matter as long as we use the same beads every time
S2 … which also are in the same place
S: As long as we use the same beads with the same colours …
[Q] T: Nice miss […]. That sounds reasonable. You are quite … And where should the beads be placed?
S: Outside
[Q] T: Where outside?
S: The same place every time.
T: Go for it
S: Yes

In Excerpt 1, it appears that the teacher does not differentiate in scaffolding means. The only mean used by the teacher was questioning. The group had a well-prepared investigation, and they were able to reply to all questions from the teacher. Excerpt 1 is placed on the right side of Figure 2 in that, the students showed a higher degree of responsibility toward their current task. The group was running almost without any support from the teacher and seemed ready to take on new and more advanced task in their learning progress. The teacher's scaffolding strategy was simple using only questioning. This could be to secure that the students actually were capable of doing their own investigations, but the absence of a complex scaffolding strategy resulted in students not going as far as they might have gone with more scaffolding means used by the teacher. Using the analytical model (Figure 2), it seems that the students were ready to take the responsibility, but the teacher was controlling the students instead of transferring responsibility.

Case 2 is an example of students working in Level 2 in the inquiry approaches where they are exploring sources of UV radiation. They finished their first investigation and seem stuck in getting ideas for new investigations. Until now, the group worked with the exercise, but the group is insecure in how to move along. The teacher approached the group to support them to do more investigations.

Excerpt 2 (teacher-student interaction, Teacher 2)

[Q] *T*: *Can you five brains unite and come up with other suggestions to where you can examine other sources if UV light radiates from it?*
S1: *Outside*
S2: *The sun … No, we cannot do that.*
[F] *T*: *Well, I don't know.*

S2: *But there is no sun at the moment.*
[H] *T*: *There isn't?*
S2: *No*
[H] *T*: *So, it is simply dark*
S2: *(nodding and smiling): Yes*
[H] *T*: *Could you examine if UV light radiates from the sun?*
S3: *Yes, if we go outside.*
S2: *Couldn't we just stick out of the window?*

The group takes a cup full of UV beads and cover them up to prevent exposure to light. The group then goes outside where they remove the cover and expose the pearls to daylight on a cloudy day.

S1: *Damn. They are colored. Wow that was fast.*
S2: *They are colored*
S3: *Yes*
S3: *Well. The experiment was a success.*

In comparison to Case 1, the transfer of responsibility was not that fully integrated at the start. A student from the group questioned if it was possible to do the inquiry outside because the weather was cloudy, and the group seemed insecure in taking responsibility. The argument was that there was then no sun light. The teacher does not directly explain that it is possible to measure UV radiation, but instead questioned their argument by saying: "There isn't?" He continued taking the full consequence of the students' view in concluding: "So it is simply dark." This was obviously not true, and he thereby brought the students into a cognitive conflict that was testable through inquiry. In this way, he prompted the group to think twice. In other words, this strategy was hinting that the group should go out anyway and find out if it works. They did this and experienced that the UV beads changed color. Using hints and feeding back as scaffolding strategy, the teacher helped the students toward their learning. This was as an example of the transfer of responsibility from the teacher to the group. The excerpt was, therefore, placed in the middle of Figure 2 on the continuum of the scaffolding process.

In the last case where Teacher 2 interacts with another group, there is yet another pattern. This group is working in Level 3 of

the inquiry approaches where they are examining the influence of sunscreens in blocking UV radiation. The group was doing their experiment in the dark. They had a UV lamp pointed at a sheet of transparent paper where different sunscreens have been put on. Underneath the paper, there were placed some UV beads.

Excerpt 3 (teacher-student interaction, Teacher 2)

[Q] *T*: *Is there sunscreen on?*
S1: *Yes*
S2: *But only on the one* (*points at the top paper*).
[Q] *T*: *Only on one? How the … Oh so you have something lying beside that too?*
S2: *Yes*
S1: *Here comes something.*
S3: *Here comes the flashlight* (*is using her mobile phone as a flashlight*)
S1: *Ehhh … It is still white. So, you can say that not much has happened.*
[H] *T*: *Yes, but if it gets colored* (*points at the white bead*) *does it then get that color* (*points at the colored bead*)*? Because there are different colors. Some get yellow, some get green and some get purple.*
S1: *But that doesn't matter as long as it has no color.*
[H] *T*: *When I took them all there were also two that did not get any color. What if you got one of those that hardly shift color? Then, it would be hard to judge.*
S2: *Then, we put some more underneath.*
[E] *T*: *It is that thing with the variables, right.*

The teacher starts with a short questioning, but very fast he changed means toward hinting. In the end, he gave them the explanation. The group then continued their work.

S4: *What if we say abracadabra? Then it might work?*
S1: *Why don't you hold 30 s above the one and then 30 s above the other? Then, you are sure that there is an equal amount on each.*
S3: *Because …*
[Q] *T*: *What is that? Is there different sunscreen or what?*
S2: *Yes*
[H] *T*: *It is like the sunscreen has different colors or what?*
S2: *These have the same color (takes two beads and tries them out under the sunscreen).*
[M] *T*: *Have any of you had a hole made at the dentist and have a plastic filling?*
S1: *Plastic?*
[M] *T*: *Yes, you know where the filling is not made of silver but of plastic.*

The teacher continued hinting, but now the group was ignoring the question and carried on with their work. The teacher then changed his mean toward modeling in trying to draw perspectives to plastic fillings at the dentist. Again, the group ignored the question and carried on their experiment.

S4: *Light S3. Light*
S2: *Light*

S3: *Uses the UV-lamp*
S4: *With the other one*
S3: *Uses the mobile phone as a flashlight*
S4:*... just that we can have a quick look*
S2: *Hold it* [*The UV-lamp*] *over again. S3 hold it over again.*
S2: *You cannot see anything. Turn on the light.*
[*Q*] *T*: *Is S3 destroying the experiment now?*
S3: *Yes, but we need some light.*
[*Q*] *T*: *Is S3 destroying the experiment now because she turns on the light?*

The teacher turns back to questioning as scaffolding mean but once again the group ignores the question.

[*H*] *T*: *Do they [the beads] get colored by the lamp in her cell phone?*
Choir: *No*
S2: *We have tried that*
S1: *We have tried that.*
[*H*] *T*: *They don't? That means: Is there some interference in that you use the light?*
S1: *No*
[*E*] *T*: *But it was like that they were certainly not supposed to get too much. But it really doesn't matter or what?*
S2 and S3: *No*
S4: *No but just in case that it should matter a tiny bit.*

This is an example of the different scaffolding means used by the teacher, but none seemed to work. The students needed a great deal of guiding and were not ready to take full responsibility of their problem solving. The teacher started with hinting by trying to make them aware of what to notice, but when he posed questions for more reflection the group started to ignore his questions. There seemed to be a cognitive load in the group where they were fully hung up with just getting their experiment to work. This showed an example where there was no fading of the teacher's support. Some accounts and actions from the group could be interpreted as a lack of understanding of what they were working with like when a student responded: "What if we say abracadabra. Then, it might work" or when the group carried on the experiment in the dark even though they had already tested that there was no impact with the flashlight. Despite the usage of a wide range of scaffolding means, the teacher was not able to guide the students toward learning from the inquiry. This placed the excerpt on the left side of Figure 2.

In summary, the scaffolding means used differently according to the groups' understandings and responsibilities in the inquiries were as noted in Table 1.

Table 1: Patterns of scaffolding means in inquiry excerpts

Excerpt	Scaffolding means
Excerpt 1	Q-Q-Q-Q-Q-Q-Q-Q
Excerpt 2	Q-F-H-H-H
Excerpt 3	Q-Q-H-H-E, Q-H-M-M, Q-Q-H-H-E

Scaffolding strategies appear in short sequences starting with questioning and then using other scaffolding means. When dealing with the students capable of doing inquiry, these means were limited to questioning, while hints seemed to be a first mean for students taking less responsibility in the inquiry. If these hints worked, the students were able to do their inquiry by themselves, but if the hints did not have an effect the teacher turned to explanation. In analyzing the scaffolding means, the findings showed the usage of all means except for instruction and that means were used differently according to students' inquiry abilities.

Analysis of Scaffolding Intentions

After the lessons, the teachers were interviewed with a focus on their reflections and attitudes regarding doing inquiry-based teaching and their scaffolding strategies to improve students' skills and competencies through such teaching. The transcripts of the interviews were analyzed for the teachers' intentions for scaffolding the students in their learning.

The analysis revealed that the main focus for the teachers in their scaffolding intentions was on students' cognitive activities while the metacognitive activities were somewhat less addressed. Students' affect as an intention for scaffolding was absent in the teachers' comments.

When the teachers addressed students' cognitive activities, the teachers become aware that there was a difference in learning concepts and learning methodology for the students. It was noted that there are two different kinds of cognition needed to learn. As Teacher 1 expressed it:

> *Because suddenly it became clear to me that some have a flair for thinking like that while others find it extremely difficult with such an open way. Actually, some of those who are insanely good with science concepts find it extremely difficult to put it into a methodological approach; and then others can easily do that – there is a transfer. It just happens, and they do not have to think about it. It is no problem and then there are those to whom it is a giant wall. So later I actually made homogenous groups in that the class was split into little nerd, middle nerd, and great nerd groups.*

The teacher found it better to put the students into such homogeneous groups so that the students could grow together from a common basis. The intentions behind were for every student to have the possibility to improve, but when this comes into practice, this pattern was a little more blurred.

Such groups needed different kinds of help and it was hard to help all students at the same time. Later in the interview Teacher 1 said:

> *Then there are the little nerd groups. They get Prisma [a textbook system with mainly exercises of limited inquiry possibilities], Prisma, and one open [exercise], and great nerd get them all open, and middle nerd ... then I can help little nerd in common with the content specific concepts.*

Then, they get these types of exercises, and little nerd can get some starting aid. They get the jumper cables. Then, we hope that after the jumper cables they can handle a little by themselves. Then, you can go to the great nerds and check their hypothesis. The middle nerd also gets going with some start aid.

Even with the intentions of giving all students the possibility to develop their competencies, the teacher chose to focus on the weaker groups and only checked on the more competent students. This was the picture seen in Excerpt 1. The intentions might be there from the teachers, but due to the major differences among the groups, the main focus for scaffolding was placed on the weakest groups.

The conditions for doing IBSE also have an impact on students' ability to reflect and enhance cognitively. The experiment has a much larger role in the lessons than it was supposed to have. Teacher 2 expressed it as follows:

Then, you take offset in something that you know about from the start; and that knowledge should – by doing some kind of experiment – be elevated to a higher level. Adding more theory, you could say. I then can have my doubt if it always happens because it is hard to go from: Well, we know something on forehand and I would like them to know more – but the experiment gets to fill very much and ends up in being the goal instead. You can say that you have to remember to do the last too [the reflections], but the experiment becomes the goal instead. That is what is difficult about the hypothesis, where you actually might do some hypothesis and do some planning of investigations, but do we actually return to the hypothesis and answer it – well do we recall it. But yes. I see IBSE a little as something where we start with some theory, then we do some experiments and after that we have gained some kind of higher level.

The experiment can sometimes be an inhibitor of the cognitive development that is the intention. Scaffolding students' learning in inquiry settings, therefore, demands a higher focus from the teacher to include the reflections on the experiment to reach a higher level. Else the focus of inquiry as a mean for learning science can end up with inquiry being the end itself (Abd-El-Khalick et al., 2004). This was what was seen in Excerpt 3, where the teacher used different means to help the students reflect on their experiments. None of these worked and the focus ended on understanding the experiment rather that the conceptual knowledge.

Focusing on metacognitive perspectives though also requires more structure from a teacher. Teacher 1 put it like this:

Actually, I have been a bit mean on my students in the way they get time for reading or ask some questions, and then they actually had …well they had the exercise in the IBSE way, but they also had the Prisma text on their computers and then I just let them decide themselves if they would make their hypothesis and try it out or if they would read

in the book. In Prisma, it says exactly what to do, and what happens is that most of them do not read and if I know that it is in the text, I have refused to tell them and instead told that now it was time for studying. "We don't know where to find it. Which reading technique shall you use to find it? I shall browse through it." OK. Then, they have to browse through it and they find the place and read more in depth in that place. Then, they think that I am really annoying. "You have to help us. You are the teacher." Well, that's what I am doing. You are learning to study. I think it is important that the students learn to read, to study, to read models and catch that side too.

The metacognitive perspective was not always obvious for the students and thereby it became an important task for the teacher to hold students in metacognitive phases even if they did not know that this was what they were doing. Such metacognitive phases though seem to be difficult to uphold during the experiment.

DISCUSSION AND CONCLUSIONS

There is limited research on teachers' scaffolding strategies toward groups with different skills in the same classroom. The purpose of scaffolding is to elevate the students' learning. In a socioconstructive setting like IBSE, Shepard (2005) argued that scaffolding and formative assessment could be viewed as the same in that both aimed at aiding students in their zone of proximal development. Looking at the literature on formative assessment and dialogic teaching shows that much research was done on whole-class discussions (Nieminen et al., 2021). Ruiz-Primo (2011) argued that informal formative assessment was a way to put forward students' thinking and from there elevating the students.

The same purpose was found in the teacher interviews in this study. Teacher intentions were to stimulate and elevate students' cognitive and metacognitive abilities, but there was not a straight line from good intentions to effective practice.

The three cases from this study illuminate the differences in student performance in inquiry-based science education. Case 1 showed students capable of doing a scientific inquiry on their own, but the excerpt from the case also showed that the scaffolding from the teacher was not bringing them to a higher level but was more a confirmation of the existing level of inquiry skills. In Case 2, there was a successful scaffolding of the students. With a little help, the students actually elevated their understanding of UV radiation, while in Case 3, there was no cognitive or metacognitive improvement despite the teacher using a multiple range of scaffolding strategies.

Nieminen et al. (2021) found that on-the-fly formative assessment in a physics classroom consisted of four steps, namely, (i) checking or examining students' thinking, (ii) correct or develop students' thinking, (iii) redirect students' thinking, and (iv) review students' thinking. The present study showed that the teachers were starting with questions to check

the thinking of the students, but from there it was very different on how to move on.

This study's findings showed that even when the teachers have the intentions of developing students' cognitive and metacognitive abilities, it was not an evenly distributed effort from the teacher according to the students' level of competencies from the beginning of the lesson. Teachers used a great deal of time trying to elevate the lowest performing groups while the better performers were controlled instead of elevated. The risk is that the students with the better abilities are left to themselves in their inquiry and are not challenged in their thinking to become even more reflective both at the cognitive and metacognitive level. It can, of course, be seen as a transfer of responsibility from the teachers toward the students, but as Dolin et al. (2018) stress, it is the responsibility of a teacher in an IBSE setting to set challenging tasks while providing scaffolding and encouraging students' critical reflections on their learning and their future applications of what was learned. By just checking the students in their planning of investigation, such responsibility from teacher can be easily forgotten.

To address this responsibility, an opportunity could be more usage of the absent scaffolding mean of direct instruction toward the weaker groups. Due to the IBSE setting, teachers find it hard to use this mean since it is in direct opposition to the essence of IBSE, but instead of beating around the bush such mean might be more helpful for students when they are not capable of planning and conducting their own investigations. As a category "Doing Science" (Hodson, 2014) is not something you just do. It is something you have to learn. As one of the teachers said, it is a way of thinking. To support the development of such thinking, a possibility is to go step-wise from limited inquiry toward open inquiry, but with intermediate steps to support students in such journey (Bell et al., 2005). As seen in the analysis of teacher interviews, one of the teachers actually tried to differentiate the task the students were doing according to the students' level of competencies, but these tasks seem to lack the intermediate steps going directly from limited inquiry to open inquiry and thereby not giving the students the opportunity to develop stepwise.

From the perspective of the three cases, the teachers – even if they were prepared beforehand – did not find it easy to transfer the responsibility and scaffold the students in this transfer. It is a new way of acting as a teacher in a classroom which demands experience and cognitive preparation from the teachers. More emphasis on specific scaffolding means in both teacher education and in-service teacher training can be a helpful tool for teachers in their new role as teachers in IBSE settings. Studies like Ruiz-Primo (2011) and Nieminen et al. (2021) have a tendency to emphasize what works. It is evenly important to be aware of what does not work in order to improve students learning. This study shows the difficulties of going from good intentions to a learning practice.

To further investigate this area of student learning and teacher scaffolding, it would be valuable to differentiate among strategy usages at different student levels. More studies on the patterns of means in scaffolding strategies could help to unfold the findings in this study and support both teacher training and in-service teacher training in the scaffolding of all students' learning.

ACKNOWLEDGMENT

ETHICAL STATEMENT

Participating students and their parents handed in of declaration of consent and there approved to volunteer for the study. All participants were informed that this declaration of consent could be withdrawn at any time. All data were anonymized for securing that neither students nor teachers could be recognized.

REFERENCES

Abd-El-Khalick, F., Boujaoude, S., Duschl, R., Lederman, N.G., Mamlok-Naaman, R., Hofstein, A., Niaz, M., Treagust, D., & Tuan, H.L. (2004). Inquiry in science education: International perspectives. *Science Education*, 88(3), 397-419.

Anderson, R.D. (2002). Reforming science teaching: What research says about inquiry. *Journal of Science Teacher Education*, 13(1), 1-12.

Areepattamannil, S. (2012). Effects of inquiry-based science instruction on science achievement and interest in science: Evidence from Qatar. *The Journal of Educational Research*, 105(2), 134-146.

Bell, R.L., Smetana, L., & Binns, I. (2005). Simplifying inquiry instruction. *The Science Teacher*, 72(7), 30-33.

Belland, B.R. (2017). *Instructional scaffolding in STEM education: Strategies and efficacy evidence*. Springer.

Belland, B.R., Kim, C., & Hannafin, M.J. (2013). A framework for designing scaffolds that improve motivation and cognition. *Educational Psychologist*, 48(4), 243-270.

Blanchard, M.R., Southerland, S.A., & Granger, E.M. (2009). No silver bullet for inquiry: Making sense of teacher change following an inquiry-based research experience for teachers. *Science Education*, 93(2), 322-360.

Crawford, B.A. (2007). Learning to teach science as inquiry in the rough and tumble of practice. *Journal of Research in Science Teaching*, 44(4), 613-642.

Dolin, J., Black, P., Harlen, W., & Tiberghien, A. (2018). Exploring relations between formative and summative assessment. In: Dolin J., & Evans, R., (Eds.), *Transforming Assessment*, Cham, Switzerland: Springer International Publishing, pp. 53-80.

European Commission (EC). (2007). *Science Education Now: A Renewed Pedagogy for the Future of Europe*. Office for Official Publications of the European Communities.

Harlen, W. (2013). Inquiry-based learning in science and mathematics. *Review of Science, Mathematics and ICT Education*, 7(2), 9-33.

Hodson, D. (2014). Learning science, learning about science, doing science: Different goals demand different learning methods. *International Journal of Science Education*, 36(15), 2534-2553.

Hsieh, H.F., & Shannon, S.E. (2005). Three approaches to qualitative content analysis. *Qualitative Health Research*, 15(9), 1277-1288.

Ireland, J., Watters, J.J., Lunn Brownlee, J., & Lupton, M. (2014). Approaches to Inquiry Teaching: Elementary teacher's perspectives. *International Journal of Science Education*, 36(10), 1733-1750.

Jonsson, A., & Svingby, G. (2007). The use of scoring rubrics: Reliability, validity and educational consequences. *Educational Research Review*, 2(2), 130-144.

Kawalkar, A., & Vijapurkar, J. (2013). Scaffolding Science Talk: The role of teachers' questions in the inquiry classroom. *International Journal of Science Education*, 35(12), 2004-2027.

Kvale, S., & Brinkmann, S. (2009). *Interviews: Learning the Craft of Qualitative Research Interviewing*. California: Sage.

Leonard, J., Boakes, N., & Moore, C.M. (2009). Conducting science inquiry in primary classrooms: Case studies of two preservice teachers' inquiry-based practices. *Journal of Elementary Science Education*, 21(1), 27-50.

Lin, H.S., Hong, Z.R., & Lawrenz, F. (2012). Promoting and scaffolding argumentation through reflective asynchronous discussions. *Computers and Education*, 59(2), 378-384.

Lotter, C., Harwood, W.S., & Bonner, J.J. (2007). The influence of core teaching conceptions on teachers' use of inquiry teaching practices. *Journal of Research in Science Teaching*, 44(9), 1318-1347.

Lunetta, V.N., Hofstein, A., & Clough, M.P. (2007). Learning and Teaching in the School Science Laboratory: An Analysis of Research, Theory, and Practice. In: Lederman, N.G. & Abel, S., (Ed.), *Handbook of research on science education*. New York: Lawrence Erlbaum. pp. 393-441.

Merriam, S.B. (1998). *Qualitative Research and Case Study Applications in Education. Revised and Expanded from "Case Study Research in Education"*. New Jersey: Jossey-Bass Publishers.

Minner, D.D., Levy, A.J., & Century, J. (2010). Inquiry-based science instruction what is it and does it matter? Results from a research synthesis years 1984 to 2002. *Journal of Research in Science Teaching*, 47(4), 474-496.

Newman, D., Griffin, P. & Cole, M., (Eds.), (1989). *The Construction Zone: Working for Cognitive Change in School*. Cambridge: Cambridge University Press.

Nieminen, P., Hähkiöniemi, M., & Viiri, J. (2021). Forms and functions of on-the-fly formative assessment conversations in physics inquiry lessons. *International Journal of Science Education*, 43(3), 362-384.

Puntambekar, S., & Hubscher, R. (2005). Tools for scaffolding students in a complex learning environment: What have we gained and what have we missed? *Educational Psychologist*, 40(1), 1-12.

Rönnebeck, S., Nielsen, J. A., Olley, C., Ropohl, M., & Stables, K. (2018). The Teaching and Assessment of Inquiry Competences. In: Dolin, J., & Evans, R., (Eds.), *Transforming Assessment*. Berlin: Springer. pp. 27-52.

Ruiz-Primo, M.A. (2011). Informal formative assessment: The role of instructional dialogues in assessing students' learning. *Studies in Educational Evaluation*, 37(1), 15-24.

Shepard, L.A. (2005). Linking formative assessment to scaffolding. *Educational Leadership*, 63(3), 66-70.

Sherin, B., Reiser, B.J., & Edelson, D. (2004). Scaffolding analysis: Extending the scaffolding metaphor to learning artifacts. *The Journal of the Learning Sciences*, 13(3), 387-421.

Stone, C.A. (1998). Should we salvage the scaffolding metaphor? *Journal of Learning Disabilities*, 31(4), 409-413.

Van de Pol, J., Volman, M., & Beishuizen, J. (2010). Scaffolding in teacher-student interaction: A decade of research. *Educational Psychology Review*, 22(3), 271-296.

Vygotsky, L.S. (1978). *Mind in Society. The Development of Higher Psychological Processes*. Cambridge: Harvard University Press.

Wood, D.J., Bruner, J.S., & Ross, G. (1976). The role of tutoring in problem solving. *Journal of Child Psychiatry and Psychology*, 17(2), 89-100.

Yazan, B. (2015). Three approaches to case study methods in education: Yin, Merriam, and Stake. *The Qualitative Report*, 20(2), 134-152.