International Journal of Science Education

ISSN: 0950-0693 (Print) 1464-5289 (Online) Journal homepage: http://www.tandfonline.com/loi/tsed20

Learning experimentation through science fairs

Jürgen Paul, Norman G. Lederman & Jorge Groß

INTERNATIONAL JOURNAL OF SCIENCE EDUCATION, 2016
http://dx.doi.org/10.1080/09500693.2016.1243272

Routledge
Taylor & Francis Group

Learning experimentation through science fairs

Jürgen Paul[a], Norman G. Lederman[b] and Jorge Groß[a]

[a]Department of Science Education, University of Bamberg, Bamberg, Germany; [b]Department of Mathematics and Science Education, Illinois Institute of Technology, Chicago, IL, USA

ABSTRACT
Experiments are essential for both doing science and learning science. The aim of the German youth science fair, *Jugend forscht*, is to encourage scientific thinking and inquiry methods such as experimentation. Based on 57 interviews with participants of the competition, this study summarises students' conceptions and steps of learning about experimentation, taking into account age disparities. Five distinct subdomains of learning were identified in which learning processes may occur. These subdomains are procedure, purpose, material, control, and time. The three separate age groups used slightly different concepts but all the participants took the same or very similar steps of learning independent of their age. Two main reasons for conceptual developments could be detected: Firstly, the participating students had the opportunity to work using methodology similar to the commonly accepted scientific path of knowledge. Secondly, due to communication processes during the competition, a purposive reflection of their own project was promoted. With respect to different educational levels, experimentation proves to be a complex scientific framework that will be learnt step by step throughout students' education. We therefore argue for a stronger anchoring of research experiments embedded in open or authentic inquiry to be included in science lessons at school.

ARTICLE HISTORY
Received 18 December 2015
Accepted 27 September 2016

KEYWORDS
Inquiry-based learning; experimentation; conceptual change; students' conceptions; learning process; science competition

Introduction

Experiments in science and science education

Inquiry-based learning is a prominent domain of science education. The term 'inquiry' here includes three different perspectives: (a) Scientists carrying out investigations using scientific methods. (b) Students learning actively by carrying out inquiry tasks like scientists. (c) Teachers providing adequate learning environments and support. Independent of the perspective, the inquiry process itself contains some core components such as scientifically oriented questions, drawing conclusions from evidence, or evaluating alternative explanations (Minner, Levy, & Century, 2010). All these aspects can coexist during experimentation, which is why experimentation is frequently addressed in the context of inquiry-based learning. Experimentation is defined as an orderly procedure carried out with the goal of testing a hypothesis by systematically manipulating the conditions of

CONTACT Jürgen Paul juergen.paul@uni-bamberg.de Department of Science Education, University of Bamberg, Markusplatz 3 (Noddack-Haus), 96047 Bamberg, Germany

the observed processes or variables to be measured (e.g. Duschl & Grandy, 2008; Griffith & Brosing, 2011). This scientific procedure generally, but not necessarily, contains the following steps: (1) formulating a research question, (2) generating a theory-based hypothesis, (3) designing the experiment, (4) conducting the experiment and collecting data, (5) preparing and evaluating the data, (6) interpretation and discussion of the results and their conclusions, and (7) communication of findings. Of course, we do not claim that this sequence is the one and only scientific method. However, there is a broad consensus nationally and internationally on the need to convey such a basic understanding of scientific thinking and working (e.g. McComas & Olson, 2002; National Research Council, 1996, 2012). Furthermore, it can smooth the way for grasping major aspects of nature of science (NOS) such as the tentative nature of scientific knowledge or the creativity among scientists, while additionally engaging students in reflection on what they have done (Abd-El-Khalick et al., 2004; Kremer, Specht, Urhahne, & Mayer, 2014; Lederman, 2007).

At school, experiments function in a variety of ways such as motivating students, testing hypotheses, or illustrating concepts (Hart, Mulhall, Berry, Loughran, & Gunstone, 2000). Here, the teacher generally knows the outcome of the experiment, whereas the result of a research experiment is unknown. However, the key element in classroom instruction is whether the teacher has communicated to students what the expected result should be. We therefore distinguish the typical 'school experiment' with explicit instructions and known results from the 'research experiment', which is part of the scientific process (in the sense of experimentation described above). Although experiments are just one type of scientific inquiry, it is still a good place to start, especially since little inquiry is usually done in schools. During science lessons, it is an additional goal to support and promote both the students' lab experience and skills of inquiry (e.g. Auchincloss et al., 2014; Bascom-Slack, Arnold, & Strobel, 2012), the measurement of which still remains a challenge for educational research (Emden & Sumfleth, 2014; Hammann, Phan, Ehmer, & Grimm, 2008). Teaching methods like inquiry-based learning or school science labs attempt to get close to real research experiments (Hofstein & Lunetta, 2004; Schwartz, Lederman, & Crawford, 2004). In this context, many publications address the different levels of inquiry, which differ in instructional aspects, for example, structured, guided, open, or authentic inquiry (Banchi & Bell, 2008; Buck, Bretz, & Towns, 2008). Projects, which launch partnerships between active researchers at university and students at school in order to find answers to their own scientific questions by experimentation, go a step further (Bardy-Durchhalter, Scheuch, & Radits, 2013).

Science competitions and science fairs

For schools, competitions, prizes, and seals of quality are increasingly gaining importance, on the one hand, to support and challenge students individually, and on the other hand, to enhance lessons and also to build the external profile of the school. This is accompanied by an increase in the number of competitions as well as by an expanding thematic spectrum of these competitions, where fields like science, engineering, and mathematics are continuing to predominate. While best-practice competitions focus on teaching staff, school administrations, or entire schools, performance competitions are supposed to speak mainly to students. Here, one can distinguish between task-oriented competitions, like the international Junior Science Olympiad, and project-centred approaches, like the German youth science fair, *Jugend forscht*.

Science fairs have a long tradition (McComas, 2011). Previous research in the context of science competitions for students focused mostly on different factors that lead to successful participation (Urhahne, Ho, Parchmann, & Nick, 2012). Here, characteristics of participants (e.g. interest in the subject, understanding of the problem, availability of knowledge, effort, experience in competitions) and influences of the students' environment (e.g. parents, teachers, additional courses offered at school) play an important role. Furthermore, gender effects among participants were found in some motivational factors such as self-concept and attributions (Feng, Campbell, & Verna, 2002; Lengfelder & Heller, 2002) or in the choice of science field (Sonnert, Sadler, & Michaels, 2013). Major predictors of willingness to participate in science competitions are self-concept, experience of competency, and previous participation (Blankenburg, Höffler, & Parchmann, 2015). Some studies addressed the question of the benefits that the students actually gain from science fairs (Abernathy & Vineyard, 2001; Sumrall & Schillinger, 2004). However, the possible learning processes, which are triggered by the participation in a contest among students, as well as the factors that are responsible for these learning processes, are largely unknown to date. In order to investigate these processes, the German science fair, *Jugend forscht*, is examined in this study.

Jugend forscht (which literally translates to 'youth does research') was initiated in 1965. Whereas the first round of the competition attracted 244 students from all over Germany, today, this competition is seen as the foremost national science youth competition with over 10,000 students participating annually (Paul & Groß, 2015). The organisation behind this competition sees the education and encouragement of young adults in mathematics, computer science, natural science, and engineering as a crucial task to provide a basis for future research and innovation in our society. The main goal of the competition is to encourage young talent in scientific thinking and working. The competition follows a periodic structure (November 30th: closing date; February: regional competitions; March/April: state competitions; May: national competition). The submitted works are small research projects carried out by students, which are more or less extensively supervised by teaching staff. Students are free to work alone or in small groups of 2–3. The time that students spend on their projects may vary. Scientific experimentation, including inquiry tasks, is most commonly at the centre of the projects. On the competition days, the students present their projects to a jury similar to the process at other science fairs.

Conceptions and steps of learning in the natural sciences

From science education publications, it is well known that the students' initial conceptions of learning opportunities play an important role in teaching and learning processes (e.g. Morrison & Lederman, 2003). These conceptions have various names in the literature depending on the perspective (e.g. preconceptions, representations; see Heddy & Sinatra, 2013; Korpershoek, Kuyper, Bosker, & van der Werf, 2013). We simply called them conceptions since we investigated conceptions of students about experimentation, which could result from classroom practice, everyday life, or a specific experience, which could moreover be scientifically correct or inadequate.

By looking not only at products of education (the outcome), but also at the process of learning, relationships between cause and effect can be detected and generalised. We understand a learning process to consist of one or more successive conceptual changes (see below). Therefore, a learning process contains at least two different conceptions, the starting and the final conception. We called these conceptions that occur in a learning process, 'steps of learning'. Steps of learning thus reflect a typical sequence of conceptions during a learning process. We consciously did not use the term 'learning progression', because this is described and used in science education literature in different ways including as (1) a developmental progression for how understanding develops, (2) increasing levels of complexity of the disciplinary knowledge and practices, and (3) pathways to support student learning (Berland & McNeill, 2010). Learning progressions have been described for various topics in science, for example, for atomic structure (Petri & Niedderer, 1998), for force and movement (Alonzo & Steedle, 2009), for the term, chemical substance (Johnson & Tymms, 2011), or for evolution (Zabel & Gropengießer, 2011). On the other hand, only few studies have been published that address learning progressions of a more general understanding of science such as scientific argumentation (Berland & McNeill, 2010) or focus on student conceptions of experimental design (Brownell et al., 2014; Dasgupta, Anderson, & Pelaez, 2014). With reference to inquiry learning, there is more consensus regarding what students should learn about scientific inquiry than how they learn it or how teachers should instruct students (Anderson, 2007; Minner et al., 2010). To teach scientific inquiry, it seems to be beneficial that one knows typical processes of learning inquiry. In this study, we therefore focus on characteristic steps of learning experimentation during a science fair in order to describe and understand the associated learning processes.

The competition, *Jugend forscht*, seems to be a suitable environment for the investigation of learning processes concerning scientific thinking and working methods, because of the defined objectives, the focus on experimentation and inquiry, and the project-centred approach of this competition. Our goal is to cast light on students' conceptions and learning processes during experimentation. To this end, the present study addresses the questions:

(1) which conceptions exist about experimentation among the participating students?
(2) how much do these conceptions change during the competition?
(3) which factors contribute towards the changes observed?

In addition, we are interested in whether there are differences in conceptions depending on age of the participants. Considering the possible influence of previous experiences with experiments, we assumed that students have difficulties in distinguishing between school experiments and research experiments (see above). The awareness of this difference is, however, considered to be a crucial basis for an advanced conceptual knowledge about scientific inquiry and natural science in general.

Theoretical framework and methodology

Reconstruction and investigation of conceptions

Our understanding of learning processes is based on constructivism (Fosnot, 2013) and a revised conceptual change approach (Chi, 2008; Strike & Posner, 1992), which considers a situated perspective (Novak, 2002). We see students as individual learners who construct their knowledge in an active and self-regulated procedure on the basis of existing conceptions. In accordance with this, the learning process cannot be controlled completely by external factors, but can be initiated by learning environments. Students thereby use their experiences and their ensuing thoughts about these experiences. Those conceptions derived from everyday experiences can be beneficial or obstructive for learning (Duit & Treagust, 1998). Thus, we understand conceptual changes as reconstructions of conceptions (Kattmann, 2008), where conceptions can be further developed, changed, or newly formed, depending on the context and the individual. In this study, we focus on students' conceptions and steps of learning considering age as an individual factor and the conditions of the competition as contextual factors.

In order to elicit students' conceptions about experimentation, two fundamentally different approaches are possible (Leach, Driver, Millar, & Scott, 1997). Students could be asked direct questions about a topic, either during an interview or using a questionnaire. In these cases, the effect of context would possibly be missing. Alternatively, students could be observed while actively engaged in experimentation. This ethnographic approach postulates that the activities of the students actually reflect their conceptions. In our study, we pursue a third, intermediate, approach by requesting students to deliberate individually on their own experiences during experimentation. For this purpose, a qualitative method using interviews is suitable, as it allows individual dialogue and reflection. The conceptions nominated by the students could thereby be related to the context of their own projects. Furthermore, especially for younger students, it is easier to describe and elucidate operations during experimentation by means of concrete examples.

Method of the retrospective query on learning processes

The diverse survey tools for research in science education entail both various possibilities and difficulties (Cohen, Manion, & Morrison, 2011). In most cases, pre-test/treatment/post-test-plans are used to investigate learning outcomes. Using a method of retrospective query into learning processes, the inquiry into the conceptions that a subject possesses before the treatment (corresponds to pre-test) can take place at the same time as the identification of conceptions that occur after the treatment (corresponds to post-test). This procedure is used as a qualitative research tool in the form of guided interviews. Since metacognition as well as attitudes and motivations concerning the learning process are gathered retrospectively, we called this method 'retrospective query on learning processes'.

The possibility of introspection (self-observation) during the retrospective query is based on accepted research methods in the field of psychology (Ellis, 1991; Kohut, 1959). Here, memories of previous situations can be verbalised in hindsight (Henry, Moffitt, Caspi, Langley, & Silva, 1994). More recent work assumes that data collected from thinking aloud or retrospective surveys possess a comparable significance to, for example, the results of a standardised performance test (Davis, 2003; Lamb & Tschillard, 2003). According to a comparative study, a retrospective test, which considers the time before the learning opportunity as a pre-test, is a more appropriate test procedure, if changes are supposed to be portrayed as they are perceived individually by the subjects (Hill & Betz, 2005). The strengths of this method of retrospective query thus lie in the clarification of the individual learning processes, while at the same time linking it to the subjects' named causes of these learning processes (cf. Côté, Ericsson, & Law, 2005; Maxwell, 2004). The method of the retrospective query also offers possibilities if, for instance, at the point of a possible pre-test, the subject group is not yet determined, whereby the conceptions before the intervention can only be accessed retrospectively. At the same time, no pre-test effect is to be expected with this method. Possible disturbances, for example, by effects of social desirability or the Hawthorne effect, cannot be excluded (Hill & Betz, 2005; McCambridge, Witton, & Elbourne, 2014), and could lead to a subjective overrating of the impact of the intervention. These effects were taken into account by using an open and problem-centred interview technique during the study.

Collection and analysis of data

The German youth science fair, *Jugend forscht*, is arranged into different local and hierarchical levels. The participants pass firstly through the regional competition, then the federal state competition, and finally, the nationwide competition. For the present research project, a total of 57 guided individual interviews were conducted during regional competition days in the years 2013 and 2014. For that purpose, all 872 participating students of five different regional competitions in Bavaria and Thuringia were contacted beforehand, concerning their willingness to be interviewed. From the 263 positive responses, 57 volunteering students from 10 to 18 years were randomly chosen for the interviews to produce an approximately equal distribution of interviewees with respect to location, age, gender, and the topic of their work with an emphasis on natural sciences (average age: 14.9 ± 2.6 years; 28 males, 29 females; topics: 19 biology, 18 chemistry, 14 physics, 2 engineering, 2 geoscience, 2 mathematics and computer science). All personalised data were made anonymous.

An interview lasted for about 30 minutes and started in a time frame of 30–60 minutes after the visit of the competition jury, during which the participants gave a short poster presentation of their work. We used a structured guideline to align the 57 interviews for reproducibility. Two different researchers conducted the interviews. The interview guideline integrates two methodological approaches: firstly, problem-oriented, open and half-open questions to collect the current conceptions about scientific experimentation and secondly, the retrospective query on the individual learning process. Several basic questions were drawn from validated questionnaires (Gaigher, Lederman, & Lederman, 2014; Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002; Schwartz et al., 2004), from which subsequent questions were built up. The interrelationship between questions and answers was validated by three different researchers based on qualitative content analysis (see Mayring, 2010). In addition, an internal triangulation process with similar questions on the same issue was integrated into the guideline. The guideline started with open questions about the science fair and the participant's project such as: 'What did you experience today?' or 'Please tell me in two or three sentences, what did you do during the work on your project?' The first section of the interview established the context of the project carried out by the participant (see above). In the second section, subjects were asked to think and reflect about their work and deduce general characteristics of scientific inquiry from their point of view. Appropriate questions were, for instance: 'How and where did you approach your work scientifically?' or 'What does experimentation mean to you?' The third section of the interview guideline linked to former experience of the participants. Questions included, for example: 'How do you experience experiments at school?' or 'What did you know about experimentation before your work at *Jugend forscht*?' Finally, within the fourth section, causes of possible conceptual changes were requested, if not already addressed before. For this purpose, we asked questions such as: 'Why did you change your conceptions about experimentation?' or 'Did your conceptions change regarding experimentation due to *Jugend forscht*?'

The interviews were captured using a voice recorder and processed according to qualitative content analysis (in line with Mayring, 2010; Seidman, 2012). This method includes the following five steps: (1) transcription of voice recordings, (2) editing transcripts (transferring students' statements into a grammatically correct form), (3) organising students' statements (summarising the same or similar statements within one interview), (4) explication (interpreting statements by identifying conceptions and underlying experiences), and (5) structuring (formulating associated concepts). For reliability, coding and interpretation of students' statements (steps 4 and 5) were analysed by two researchers working independently. The findings of both were then reconciled if necessary. The organised statements of the students were summarised into tables, where the conceptions mentioned retrospectively were differentiated from the current conceptions. By comparing these conceptions, we were able to construct the learning process on the basis of the detected conceptual changes or the additionally accrued concepts. In order to reconstruct the sequences of the learning processes, the concepts identified were linked with each other step by step according to the conceptual changes made by the subjects. We then separated three groups of participants that differ in age to enable comparisons of their respective concepts and sequences of learning processes (group #1: 10–12 years old, $n = 17$; group #2: 13–15 years old, $n = 18$; group #3: 16–18 years old, $n = 22$).

Results

Students' statements about experimentation

Five examples are quoted to represent typical students' experiences and their associated statements about experimentation. Sophia, a ten-year-old, experiences experiments in school differently from the ones at *Jugend forscht* (see Table 1, example 1). During the experiments in school, she is mostly only a spectator, where the teacher presents experiments as a demonstration for the entire class. At *Jugend forscht*, Sophia not only takes matters in her own hands, she also does so without explicit guidelines from the teaching staff and without written instructions. Fifty-four of the 57 students questioned usually carry out experiments at school as part of a group, or with a partner following written instructions (see also Table 1, example 4).

The 15-year-old Emily gives information about her individual learning process (see Table 1, example 2). Formerly, Emily saw experiments as entertaining; they were rather

Table 1. Five representative student statements from the 57 individual interviews conducted about the different aspects of experimentation (extracts from the original transcripts, key passages are marked as shaded text, the time display is given in hours:minutes:seconds).

1. Experiments in School and at *Jugend forscht*	
Sophia (10 years old) investigated why honey sticks like a glue using a microscope.	
00:12:19	*Interviewer:* 'How do you experience experiments in school?'
00:12:23	*Sophia:* 'We had an experiment in biology. Our biology teacher did that. He tested what would burn down fastest. And we simply watched. He dipped a tissue into oil and one was normal. And then we watched. (…)'
	Interviewer: 'And how do you see experimentation at *Jugend forscht*?'
00:13:17 00:13:22	*Sophia:* 'Differently. Also, we did everything alone. Without a teacher, without a guideline on a piece of paper how you're supposed to do it. But simply freely.'
2. Learning processes for the purpose of experimentation	
Emily (15 years old) produced bioplastics and examined their characteristics compared to normal plastics	
00:27:53	*Interviewer:* 'What did you know about it before you did your *Jugend forscht* assignment?'
00:27:59	*Emily:* 'I definitely had a different understanding of experiments. That changed during *Jugend forscht*. (…) Before, I always thought it was really amusing, with explosions and stuff. (…) But it can also happen that you have setbacks or that nothing happens during an experiment. (…)'
00:29:21	*Interviewer:* 'Earlier on you said that you learned something. Would you please summarize, what did you learn about science through *Jugend forscht*?'
00:29:28	*Emily:* 'I learned about science that experiments can be different than you expect, that science doesn't always have to be theoretical stuff, but that you can prove things by yourself, that it can be really fun, that you can understand it. And that you can still explore a lot, that not everything is proven yet.'
3. Material and control during experimentation	
Michael (14 years old) carried out experiments with bicycle tyres varying tyre pressure.	
00:06:24	*Interviewer:* 'For you, what belongs to an experiment?'
00:06:29	*Michael:* 'So first of all an experimental setup with all the materials that you need. (…) Then you have to work very precisely during experimentation and every experiment has to be replicated several times so that you can rule out mistakes. (…)'
4. Relationship between instruction and documentation	
Jessica (12 years old) dyed clothes using plant pigments.	
00:11:42	*Interviewer:* 'What do you think is important for experimentation?'
00:11:47	*Jessica:* 'A good documentation, because you easily forget what you have done. (…) I was used to do experiments according to written instructions and with given materials. At *Jugend forscht* we diverged from these instructions and made things different. (…) So we had to document our experiment more precisely and write down an experimental protocol, otherwise we would not have known what we had done, because we had no instructions any more for our experiments.'
5. Subdomains of learning depend on each other	
Nick (17 years old) investigated whether sunlight could be replaced by other radiation as a source of energy in photosynthesis.	
00:28:17	*Interviewer:* 'You mentioned before that you learned something about experimentation. What did you learn about it?'
00:28:26	*Nick:* 'Mainly that you need a question. (…) If you want to work scientifically, you need your own question. The question determines your experiment and all the stuff required. (…) Real scientists may often use more precise and more expensive devices, but this is actually not necessary to work scientifically. And when you have a question, you also know why you are doing that experiment, in order to answer that question, not just for fun like you did it at school several times. It can be fun, too, of course.'

'amusing' and spectacular ('explosions'). During the course of the competition, *Jugend forscht*, it became clear to her that experimentation can be discouraging, that you can have 'setbacks' or that sometimes 'nothing happens'. Experiments can be 'different than you expect' and with them you can 'prove things'. With this, Emily is an example of the learning process from the conception that experiments serve as entertainment, towards the conception that the purpose of experimentation lies in knowledge production.

For 14-year-old Michael, the experimental set-up and the material necessary for it belong to experiments (see Table 1, example 3). Twenty-three of the 57 students questioned associate experiments with very specific objects and materials (e.g. 'white lab coats', 'coloured fluids', 'electronic instruments'). Moreover, Michael sees working precisely and carrying out multiple repetitions as very important for experimentation. The conception that real scientists have to work very precisely is shared by 55 of the 57 participants interviewed at the competition.

Twelve-year-old Jessica believed that documentation is crucial for experimentation (see Table 1, example 4). She was used to carrying out experiments 'according to written instructions and with given materials'. In the context of the science fair, she tried variations of known experimental instructions. After consideration of her procedure, she concluded that documentation is necessary to be able to reproduce the changes to the experiment. Nick, who was 17 years old, emphasised the importance of questions (see Table 1, example 5). In addition, he stated that the question determines the experimental set-up and clarifies the aim of an experiment. Jessica and Nick also provide evidence that students linked different aspects of experimentation together. The five students, Sophia, Emily, Michael, Jessica, and Nick, represent typical conceptions of experimentation found in this study.

Concepts about experimentation and age differences

The findings shown in Figures 1–4 are described in this paragraph. These figures indicate concepts and steps of learning about experimentation. Single concepts in each table are numbered consecutively as shown on the left side of each figure. Learning processes are performed from bottom to top. There are three columns, one for each of the different age groups. Dark grey cells on the left of each column show the number of participants who held the respective concept before the science fair (retrospective view). The light grey cells on the right of the columns show the number of participants who revealed the respective concept on the day of the competition (during the interview). The arrows on the right-hand side of the figures indicate the approximation to scientific concepts (scientific inquiry). Diagonal grey lines between dark grey cells and light grey cells represent conceptual changes achieved by a specific number of students (small numbers).

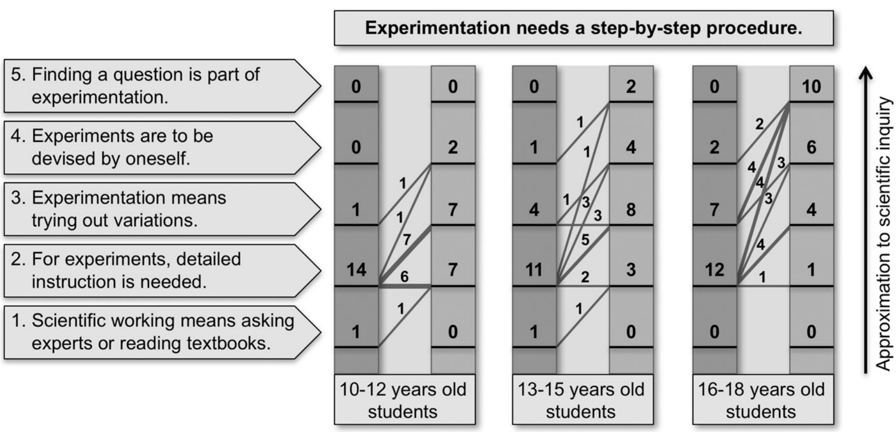

Figure 1. Concepts (#1–5) and steps of learning about experimentation representing the main concept 'procedure', $n = 54$. See text for further details (concepts about experimentation and age differences).

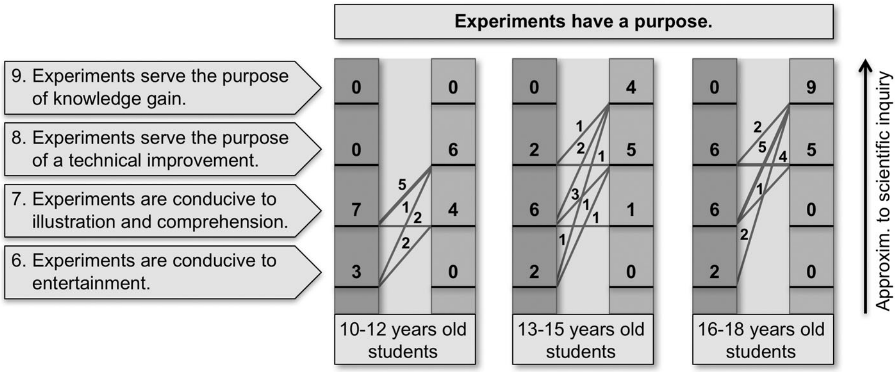

Figure 2. Concepts (#6–9) and steps of learning about experimentation representing the main concept 'purpose', $n = 34$ (see text for further details).

Horizontal grey lines imply that concepts did not change. If diagonal grey lines are steep, the respective students usually negotiated more steps successively.

Participants in the competition had a sophisticated understanding of experimentation, and thus they mentioned very different features. In total, we found 20 different concepts regarding experimentation (#1–18 see Figures 1–4, left column; #19–20 see text below). Further analysis of the students' statements and formulation of the concepts at a higher level of abstraction reveal five generalised concepts, which arrange and summarise the 20 concepts arising from the specific and concrete experiences of the students. Hence, we designate those generalised concepts as 'main concepts'. These main concepts are: (1) Experimentation needs a step-by-step *procedure*. (2) Experiments have a *purpose*. (3) Experiments need *materials*. (4) An experiment requires a *control*. (5) Experimentation takes *time*. These five main concepts were not determined before we carried out the interviews, for instance, derived from a theory or the literature. In addition, they were not embedded as a structure provided in the guided interview. On the contrary, those main concepts arise from empirical data. During the interviews, 52 of the 57 participants commented on the three main concepts '*procedure*', '*material*', and '*control*', while responding

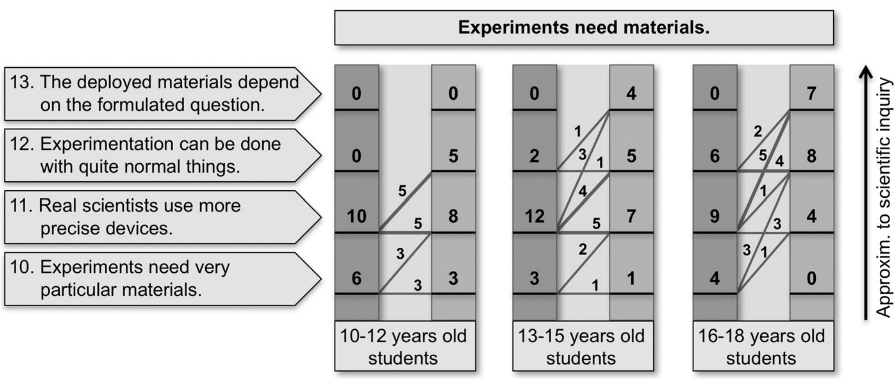

Figure 3. Concepts (#10–13) and steps of learning about experimentation representing the main concept 'materials', $n = 52$ (see text for further details).

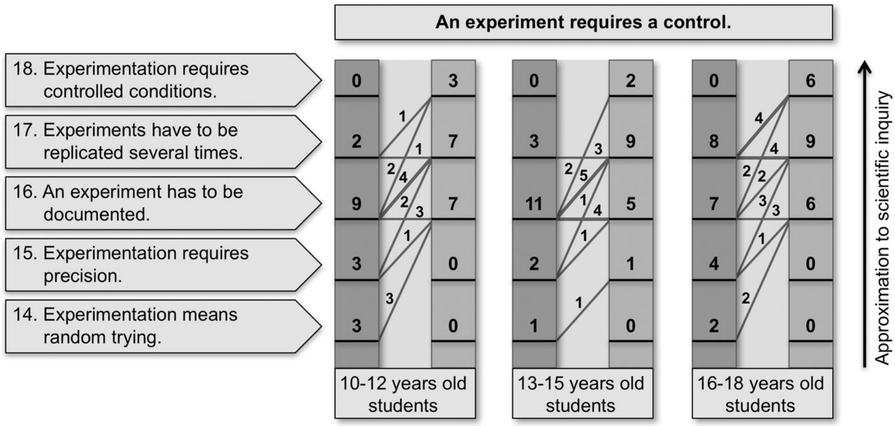

Figure 4. Concepts (#14–18) and steps of learning about experimentation representing the main concept 'control', $n = 55$ (see text for further details).

to their conceptions regarding experimentation (Figures 1, 3, 4). Thirty-four participants mentioned the '*purpose*' of experimentation (Figure 2). The fifth main concept '*time*' was only addressed by 12 subjects. This main concept also contains only two concrete concepts, which are firstly 'experiments need little time', and secondly 'experiments are elaborate and need patience'.

Considering age, we found differences in the incidence of concepts used within three main concepts, which are procedure, purpose, and materials (Figures 1–3). The concepts regarding the procedure typically used by students aged 10–12 were #2 (detailed instruction) and after the experience of the competition, also #3 (trying out variations; see also Table 1, example 4). Students aged 16–18 years started with concepts #2 and #3 with some progression to higher levels, #4 (devised by oneself) and #5 (finding a question). Concepts mentioned by students aged 13–15 years included the full range previously described. A very similar picture is observed when looking at purpose and materials (Figures 2 and 3). Before the competition, younger students were used to seeing the purpose of experiments as illustration, comprehension (#7), or entertainment (#6). On the day of the interviews, these students mostly said that experiments are usually employed for technical improvements (#8). Only older students mentioned the concept that experiments serve the purpose of knowledge gain (#9). In addition, only older students see that the materials utilised during experimentation depend on the formulated question (#13; see also Table 1, example 5), whereas after the competition, younger students, in particular, believe that very specific materials are needed for experiments, like 'white lab coats' or 'coloured fluids'. We did not find such differences between age groups in terms of the concepts, control, and time.

Conceptual changes, denominated causes, and general trends

Several of the interviewees reported that their conceptions changed during the course of the competition. Some of these changes reflect replacements of previous concepts with new concepts. Alternatively, new concepts arose in addition to the previous concepts or merely modified or complemented the existing concepts. When participants changed their conceptions, this change always happened within the five main concepts found (see above). A single conceptual change did not span different main concepts. The conceptual changes observed (see Figures 1–4) are discussed below.

With the help of the retrospective query on learning processes, we could not only detect conceptual changes, but also examine the corresponding cause–effect relationships of the underlying learning processes. By means of three selected conceptual changes (Figure 5), the learning processes that have arisen are exemplified. Before they participated in the *Jugend forscht* competition (including the preparation for the competition), 37 of the 57 students interviewed believed that scientific working meant 'hands-on experimentation according to explicit instruction'. On the day of the interview, they partly associated different conceptions with it (Figures 1 and 5), for example, that you usually come up with 'real scientific experiments' by yourself, rather than working by the book or according to instructions. Here, a learning process took place that expressed an alternative or more developed understanding of experimentation.

Concerning time and effort, 12 of the 57 respondents retrospectively evaluated experiments as quick to carry out and requiring little effort. At the time of the interviews, however, 11 out of these 12 respondents noted that 'real experiments' required quite a lot of time and effort (Figure 5). The conceptions of the purpose of experimentation also changed to some extent in a number of cases. While for the participating students experiments had earlier served primarily as illustration, they realised in the course of the competition that the meaning of experiments lies in gaining knowledge (Figure 5; cf. Table 1, example 2). In the first case (purpose is illustration), the subjects simultaneously presumed that the outcome of the experiment is known from the experts in advance, whereas in the second case (purpose is knowledge gain), the course of the experiment is not known from both the participants and the experts beforehand.

In summary, we extracted 20 different concepts about experimentation. These 20 concepts were assigned to five main concepts. Since concepts and main concepts have not

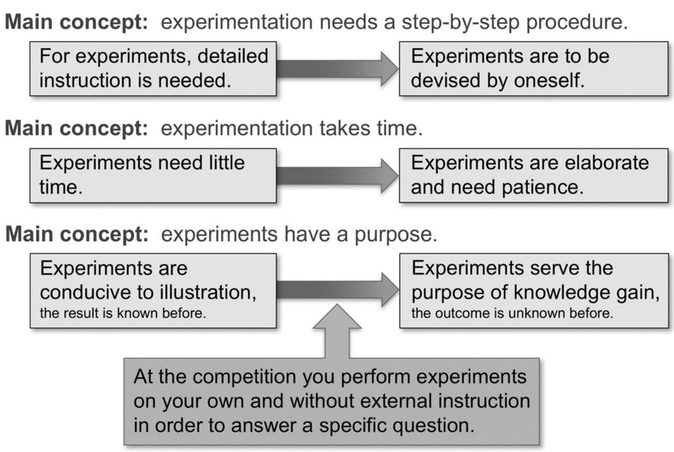

Figure 5. Three of the occurred conceptual changes within the main concepts 'procedure', 'time', and 'purpose' (retrospectively detected concepts left, concepts during the interview right, nominated cause below).

been derived from theory or literature but from empirical data, they reflect students' understanding of experimentation, which is not expected to be consistent and exclusive in all cases (see discussion). Of the 57 subjects, 9 did not show any change of conception within the five main concepts. Irrespective of age, 42 of the 54 participating students showed a conceptual change within the main concept, procedure (Figure 1). Twenty-six of 34 participants changed their conceptions regarding the purpose of experiments (Figure 2). Within the main concept, material, we detected conceptual changes for 30 of 52 students (Figure 3), within the main concept, control, for 37 of 55 students (Figure 4). According to our classification of the concepts, all students, who revealed any conceptual change, developed their conceptions towards a scientific understanding of experimentation.

Often, the students justified their conceptual changes themselves without further inquiry during the interview and brought a specific factor into play. Also if one asked them explicitly to what they ascribed their conceptual changes (e.g. 'Why do you think you have a different conception now?') one received the same two answers irrespective of age. These were (1) firstly to participate in the competition, *Jugend forscht*, they had to, according to their statements, think of their own experimental set-up or search for their own question or topic. The students had to think and act scientifically and independently, by performing experiments not only on their own, but also without external explicit instructions (cf. Table 1, example 1). (2) As a second factor for observed conceptual changes, the respondents mentioned the exchange of information on an individual basis. During the work on their own project, the students were able to exchange ideas about their work predominantly with their teachers as well as, during the competition day, with like-minded participants, visitors, and the jury. With this, they had the possibility to compare their conceptions about experimentation with others several times.

Discussion

Steps of learning experimentation

We understand conceptual change as a learning process (see above). If a student experiences a sequence of conceptual changes, the learning process contains different steps of learning. During the analysis of the concepts found about experimentation, we extracted five different main concepts. Participants' conceptual changes were found to occur only within these five main concepts, never between them. Thus, we labelled these main concepts as subdomains of learning experimentation. An individual learning process, which contains several steps, can thereby be described by moving through the different subdomains of learning. As the fifth main concept (time and effort) contained only two different concepts, further illustration is unnecessary. For the other four main concepts, the identified learning steps are summarised in Figures 1–4. We designated the related subdomains of learning as 'procedure', 'purpose', 'material', and 'control'.

For the subdomain 'procedure', students believe that scientific work usually means that 'existing experimental instructions are executed by oneself' (Figure 1; cf. concept #2). This usually corresponds to their experiences at school (school experiment). They also reported that 'asking experts or reading textbooks' was always a part of doing science and that this was the preferred method before their career as a young researcher at the science fair. A comparison of the steps of learning shown in Figure 1 with our understanding of the scientific approach during experimentation reveals that cumulative learning has taken place. In Germany, students' exercise books frequently show reports on the experiments, which are structured according to **e**xecution, **o**bservation, and **r**esult (e/o/r). Optionally, there may also be a **d**iscussion of limitations (e/o/r/d). In this way, students vary known experiments to eliminate possible prior sources of error (Figure 1; cf. concept #3). Alternatively, they may vary a previously constant variable to get comparable results for **d**iscussion. In the next step, the students orientate their experiments towards a **h**ypothesis (cf. concept #4; h/e/o/r/d). In the last of these steps of learning, they additionally develop their own **q**uestion (cf. concept #5; q/h/e/o/r/d), whereby the experimental procedure can be described in accordance with scientific inquiry. When participants expressed concept #5, this always implied knowledge of the other aspects in the sense of a sequence during scientific experimentation (q/h/e/o/r/d). This reflects the experience of a research experiment with an unknown outcome to answer a specific question. The students were thus aware of the 'scientific method,' even if this is not the only way of working scientifically. In several cases, regarding the other subdomains of learning, we placed the concepts found for one subdomain into an order, where the step above contains the steps below according to the statements of the students (for example, concept #5), apart from cases where concepts exclude each other. In doing so, the order of the concepts in Figures 1–4 reflects a step-by-step approximation to a scientific understanding of experimentation.

The subdomains of learning obviously depend on each other (e.g. Table 1, examples 4, 5). This means that often a learning process within one subdomain also accompanies a conceptual change in another subdomain. The central subdomain of learning is the 'procedure'. If a conceptual change is executed here, this usually causes a conceptual change, for example, regarding 'purpose' or 'material' as well. If during experimentation there is a question in the foreground, the purpose of an experiment is rather seen in the knowledge gain (cf. mentioned causes, Figures 2 and 5), or the dependence of the applied material on the question (Figure 3).

The conception that real scientists (in most cases) use more precise devices reflects reality and therefore cannot be graded as false (Figure 3). However, that the formulated question decides on the applicable method (and with that on the devices) corresponds better to a scientific understanding of inquiry. It may be the case in scientific practice that the technical possibilities of a working group determine the formulation of their questions rather than the other way around, or that due to new technical achievements, for example, a particle accelerator, an experiment may uncover a previously unobserved phenomenon without a specific hypothesis. Here, the results may be new discoveries with a subsequent formulation of a question.

Where the 'purpose' is concerned, the interviewees based their understanding on their experiences of experiments from the media or at school, in which experiments are often presented as entertainment or for the purposes of illustration (Figure 2; cf. school experiment). The predominant conception of the purpose of an experiment is that of an engineer who aims for a desired result, perhaps a technical optimisation. The finding that students understand experimentation as designed to produce a desired effect or phenomenon aligns with previous surveys (Hammann & Mayer, 2012). A scientist, on the other hand, aims for insight and understanding (cf. research experiment).

The concepts of the subdomain 'control' are not mutually exclusive with one exception (Figure 4): 'random trying' contradicts, at least partially, the 'organised procedure with controlled conditions'. Apart from that, the described individual concepts complement each other cumulatively. If, for example, the necessity of documentation of an experiment was realised, it was also clear to the subject that they had to work precisely during an experiment. Under 'controlled conditions', the students actually understood the adequate professional distinction of dependent, independent, and confounding variable, which is why we designate this conception as oriented to scientific experimentation.

Overall, it is remarkable that in no case did students' comprehension regress, which has also been demonstrated in other contexts (e.g. Zabel & Gropengießer, 2011). If a conceptual change occurred within the scope of the *Jugend forscht* competition, then it always took place towards a more scientific view of inquiry. In addition, another general trend is clear: many of the conceptual changes identified reflect the experience of a research experiment rather than a school experiment. Within the subdomains procedure and purpose, this is obvious (see above); however, within the subdomains, material and control, one can also interpret the findings in this way, for example, the transition of concepts #10 via #12 to #13 or the development of concept #17.

Experimentation and levels of inquiry

The acquisition of experimental expertise is an important objective in science education. Previously developed models and tests to describe and register experimental expertise focus on the 'procedure' of experimentation (Hammann et al., 2008). Furthermore, from prior work, we know that students often carry out experiments without formulating a hypothesis (Schauble, Klopfer, & Raghavan, 1991) and usually have problems generating an appropriate scientific question (Hofstein, Navon, Kipnis, & Mamlok-Naaman, 2005). This also turns out to be the most advanced skill among the students who participated in the science fair: only 12 of 57 subjects expressed a corresponding conception (Figure. 1). When the idea of formulating a question as an essential component of experimentation is developed, the subjects distinguish deliberately between a school experiment and a research experiment. They then identify two types of experimentation with diverse qualities (Chinn & Malhotra, 2002). Depending on the context, the appropriate concept is recalled and applied to the respective situation (Novak, 2002). Besides the scientific 'procedure', our results also bring other facets of learning processes pertaining to experimentation to light, such as 'purpose', 'material', and 'control'. The path of a student thus does not follow one subdomain, but contains multiple subdomains. Similarly, a multidimensional learning progression was suggested for the nature of matter (Smith, Wiser, Anderson, & Krajcik, 2006; Stevens, Delgado, & Krajcik, 2010).

Does age matter when learning experimentation? Yes and no. Yes, because differences were found in the occurrence and use of concepts among the three age groups we separated (cf. results). At first glance, older students revealed more scientifically oriented conceptions than younger students did. This is comparable, for instance, to children's use of earth shape models, such as 'disc earth', 'hollow sphere', or 'sphere' (Vosniadou & Brewer, 1992), whereby older children adopted scientifically adequate models more frequently. However, in some way, age did not matter, because all the participants followed the same or very similar steps of learning independent of their age (Figures 1–4). Hence, this difference in adoption of concepts based on age reflects that learning processes are taking place over time. The disparity simply results from the different positions of the students following the same steps of learning. If the students had the same starting position, they took the same subsequent steps during learning progress independent of their age, except for a few cases where students skipped single steps (Figures 1–4). Additionally, all students nominated the same two basic reasons for their learning progress, regardless of age (cf. results). Both reasons contain several single aspects, which can help students to make further progress depending on the individual position (e.g. error discussion, orientating towards a hypothesis; see above). As a crucial aspect of understanding science, scientific experimentation is therefore not coupled with a specific educational level, but has to be seen as a complex scientific framework that will be learnt step by step during the student's education.

Experimentation is very well suited for learning scientific inquiry, although it is only one possible type of inquiry. It does not yield a comprehensive view of the varied types of inquiry, but it is a start and a platform for future, more sophisticated, understandings. Within the subdomain procedure, the identified steps of learning experimentation almost perfectly corresponded to the different levels of inquiry described in the literature (e.g. Buck et al., 2008): Concept #2 matches 'structured inquiry', #3 fits with 'guided inquiry', #4 correlates with 'open inquiry', and #5 coincides with 'authentic inquiry'. This correspondence could reflect either different levels of instruction provided by supervising teaching staff or native steps of learning experimentation or both. In any case, students stated the possibility of open-ended experimentation as one of two reasons for any of their conceptual changes (cf. results). Our findings therefore support the perception that students benefit immensely from open or authentic inquiry (Berg, Bergendahl, Lundberg, & Tibell, 2003). However, most participants improved their conceptions only by a single step within one subdomain. This again suggests a step-by-step learning of inquiry where learning opportunities are in compliance with students' current starting positions but independent of their age.

The impact of open outcome experiments and reflection

Learning processes that lead to the basic skills of scientific experimentation are usually linked to problem-based or inquiry-based learning (Albanese & Mitchell, 1993; Kipnis & Hofstein, 2008; Klahr, 2000). The findings of our study indicate that these students, particularly due to the experience of independent, free and open outcome experimentation, as practised at the science fair, *Jugend forscht*, are performing the final steps to understand scientific inquiry. Due to their very full timetables, in Germany and elsewhere, teachers often resort to forms of teaching that leave little room for scientific experimentation with real student responsibility. Instead, they concentrate on teaching single methods or techniques, easily verifiable knowledge, or working through of cook-book-like test regulations (Minner et al., 2010). Students can then handle the experience of typical school experiments (e/o/r, see above) in two ways: either it provides an unchanged conception also of the scientific research experiment, whereby the students remain at an inadequate conception, or, they realise that there has to be a difference between school and research experiments. It then requires further experience to generate and consolidate an appropriate conception of a research experiment. According to our previous assumption, students thus have difficulties distinguishing between the two types of experiments without the personal experience of a research experiment.

In science lessons at school, experiments have diverse functions. Accordingly, different variations of experimentation should be taught. In some cases, the prepared school experiment is advantageous, because it takes up little time in the lesson and safety aspects can easily be determined. The great benefit of research experiments with an open outcome, where the students hold the responsibility, is creating a learning opportunity that initiates a fundamental understanding of science. During these experiments, all the aspects of scientific experimentation mentioned at the beginning of this article can be conveyed. Teachers should thus perform both the typical school experiment and the research experiment and emphasise the differences between them. Experimentation contains cumulative learning processes. Thus, looking at inquiry from the teacher's perspective, teachers should proceed step by step, providing increasing student responsibility considering the individual starting positions of students (see above). They should also create the possibility of exchange and reflection. This turned out to be the second reason for the progress achieved during the science competition, besides working on their own and taking responsibility for the experiment. Students learned about science because they were asked to reflect on what they have done. Some other studies also pointed out that reflection phases, for example, about the aim or the method of an experiment prior to its actual implementation, were highly conducive to learning (Khishfe & Abd-El-Khalick, 2002; Scharfenberg & Bogner, 2011). Since reflection is not often asked of students in school science, the increase of reflection seems to be an efficient way to improve classroom practice.

The science fair, *Jugend forscht*, provides opportunities for two requirements supporting learning: Firstly, according to their statements, the participants have the opportunity to work using methodology similar to the commonly accepted scientific path of discovery of knowledge. Secondly, the variety of exchanges at the competition and the support of the attending teachers lead to a conscious reflection of their own work. We detected both as reasons for advances in learning experimentation, independent of age. Although not all the participants could benefit from these possibilities to the full extent, the competition, *Jugend forscht*, meets its claim to improve students' conceptions about experimentation and to encourage young talents in scientific thinking and working such as inquiry tasks. Thus, looking at inquiry from the scientist's perspective, the science fair gives students more exposure to authentic science than what normally occurs in school. Nevertheless, the science fair approach still provides a limited view of science, which mostly teaches students about experimental design. In addition, experimentation is, of course, only one type of inquiry. However, as a consequence of our results focusing on experimentation, we argue for a stronger anchoring of research experiments with an open outcome also in science lessons at school, for the more conscious distinction from a typical school experiment, and moreover, for enhancing reflection.

Acknowledgment

We thank the foundation *Jugend forscht e.V.* for cooperation during our research project, particularly Dr. Sven Baszio (managing director), Sigrid Müller-Balhorn (head of competition management), and Stefan Gagel (head of one regional competition).

Disclosure statement

No potential conflict of interest was reported by the authors.

References

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

Abernathy, T. V., & Vineyard, R. N. (2001). Academic competitions in science: What are the rewards for students? *The Clearing House: A Journal of Educational Strategies, Issues and Ideas*, *74*(5), 269–276.

Albanese, M. A., & Mitchell, S. (1993). Problem-based learning: A review of literature on its outcomes and implementation issues. *Academic Medicine*, *68*(1), 52–81.

Alonzo, A. C., & Steedle, J. T. (2009). Developing and assessing a force and motion learning progression. *Science Education*, *93*(3), 389–421.

Anderson, R. (2007). Inquiry as an organizing theme for science curricula. In S. Abell & N. Lederman (Eds.), *Handbook of research on science education* (pp. 807–830). Mahwah, NJ: Lawrence Erlbaum Associates.

Auchincloss, L. C., Laursen, S. L., Branchaw, J. L., Eagan, K., Graham, M., Hanauer, D. I., & Dolan, E. L. (2014). Assessment of course-based undergraduate research experiences: A meeting report. *CBE-Life Sciences Education*, *13*(1), 29–40.

Banchi, H., & Bell, R. (2008). The many levels of inquiry. *Science and Children*, *46*(2), 26–29.

Bardy-Durchhalter, M., Scheuch, M., & Radits, F. (2013). Identifying deep sea gastropods in an authentic student-scientist-partnership-learning to deal with identification. *International Journal of Biology*, *3*(1), 45–62.

Bascom-Slack, C. A., Arnold, A. E., & Strobel, S. A. (2012). Student-directed discovery of the plant microbiome and its products. *Science*, *338*(6106), 485–486.

Berg, C. A. R., Bergendahl, V. C. B., Lundberg, B., & Tibell, L. (2003). Benefiting from an open-ended experiment? A comparison of attitudes to, and outcomes of, an expository versus an open-inquiry version of the same experiment. *International Journal of Science Education*, *25*(3), 351–372.

Berland, L. K., & McNeill, K. L. (2010). A learning progression for scientific argumentation: Understanding student work and designing supportive instructional contexts. *Science Education*, *94*(5), 765–793.

Blankenburg, J. S., Höffler, T. N., & Parchmann, I. (2015). Naturwissenschaftliche Wettbewerbe – Was kann junge Schülerinnen und Schüler zur Teilnahme motivieren? *Zeitschrift für Didaktik der Naturwissenschaften*, *21*(1), 141–153.

Brownell, S. E., Wenderoth, M. P., Theobald, R., Okoroafor, N., Koval, M., Freeman, S., & Crowe, A. J. (2014). How students think about experimental design: Novel conceptions revealed by in-class activities. *BioScience*, *64*(2), 125–137.

Buck, L. B., Bretz, S. L., & Towns, M. H. (2008). Characterizing the level of inquiry in the undergraduate laboratory. *Journal of College Science Teaching*, *38*(1), 52–58.

Chi, M. T. (2008). Three types of conceptual change: Belief revision, mental model transformation, and categorical shift. In S. Vosniadou (Ed.), *International handbook of research on conceptual change* (pp. 61–82). New York, NY: Taylor & Francis.

Chinn, C. A., & Malhotra, B. A. (2002). Epistemologically authentic inquiry in schools: A theoretical framework for evaluating inquiry tasks. *Science Education*, *86*(2), 175–218.

Cohen, L., Manion, L., & Morrison, K. (2011). *Research methods in education*. Oxford: Routledge.

Côté, J., Ericsson, K. A., & Law, M. P. (2005). Tracing the development of athletes using retrospective interview methods: A proposed interview and validation procedure for reported information. *Journal of Applied Sport Psychology*, *17*(1), 1–19.

Dasgupta, A. P., Anderson, T. R., & Pelaez, N. (2014). Development and validation of a rubric for diagnosing students' experimental design knowledge and difficulties. *CBE-Life Sciences Education*, *13*(2), 265–284.

Davis, G. A. (2003). Using a retrospective pre-post questionnaire to determine program impact [electronic version]. *Journal of Extension*, *41*(4), 1–8.

Duit, R., & Treagust, D. F. (1998). Learning in science: From behaviourism towards social constructivism and beyond. In B. J. Fraser & K. G. Tobin (Eds.), *International handbook of science education* (pp. 3–25). London: Kluwer Academic.

Duschl, R. A., & Grandy, R. E. (2008). *Teaching scientific inquiry: Recommendations for research and implementation*. Rotterdam: Sense.

Ellis, C. (1991). Sociological introspection and emotional experience. *Symbolic Interaction*, *14*(1), 23–50.

Emden, M., & Sumfleth, E. (2014). Assessing students' experimentation processes in guided inquiry. *International Journal of Science and Mathematics Education*, *14*(1), 29–54.

Feng, A. X., Campbell, J. R., & Verna, M. A. (2002). Understanding gender inequity in America: Interviews with academic olympians. *Journal of Research in Education*, *12*, 93–100.

Fosnot, C. T. (2013). *Constructivism: Theory, perspectives, and practice*. New York, NY: Teachers College Press.

Gaigher, E., Lederman, N., & Lederman, J. (2014). Knowledge about inquiry: A study in South African high schools. *International Journal of Science Education*, *36*(18), 3125–3147.

Griffith, W. T., & Brosing, J. W. (2011). *The physics of everyday phenomena* (7th ed.). New York, NY: McGraw-Hill Science/Engineering/Math.

Hammann, M., & Mayer, J. (2012). Was lernen Schülerinnen und Schüler beim Experimentieren? *Biologie in unserer Zeit (BiuZ)*, *42*, 284–285.

Hammann, M., Phan, T. T. H., Ehmer, M., & Grimm, T. (2008). Assessing pupils' skills in experimentation. *Journal of Biological Education*, *42*(2), 66–72.

Hart, C., Mulhall, P., Berry, A., Loughran, J., & Gunstone, R. (2000). What is the purpose of this experiment? Or can students learn something from doing experiments? *Journal of Research in Science Teaching*, *37*(7), 655–675.

Heddy, B. C., & Sinatra, G. M. (2013). Transforming misconceptions: Using transformative experience to promote positive affect and conceptual change in students learning about biological evolution. *Science Education*, *97*(5), 723–744.

Henry, B., Moffitt, T. E., Caspi, A., Langley, J., & Silva, P. A. (1994). On the "remembrance of things past": A longitudinal evaluation of the retrospective method. *Psychological Assessment*, *6*(2), 92–101.

Hill, L. G., & Betz, D. L. (2005). Revisiting the retrospective pretest. *American Journal of Evaluation*, *26*(4), 501–517.

Hofstein, A., & Lunetta, V. N. (2004). The laboratory in science education: Foundations for the twenty-first century. *Science Education*, *88*(1), 28–54.

Hofstein, A., Navon, O., Kipnis, M., & Mamlok-Naaman, R. (2005). Developing students' ability to ask more and better questions resulting from inquiry-type chemistry laboratories. *Journal of Research in Science Teaching*, *42*(7), 791–806.

Johnson, P., & Tymms, P. (2011). The emergence of a learning progression in middle school chemistry. *Journal of Research in Science Teaching*, *48*(8), 849–877.

Kattmann, U. (2008). Learning biology by means of anthropomorphic conceptions? In M. Hammann, M. Reiss, C. Boulter, & S. D. Tunnicliffe (Eds.), *Biology in context: Learning and teaching for the twenty-first century* (pp. 7–17). London: Institute of Education.

Khishfe, R., & Abd-El-Khalick, F. (2002). Influence of explicit and reflective versus implicit inquiry-oriented instruction on sixth graders' views of nature of science. *Journal of Research in Science Teaching*, *39*(7), 551–578.

Kipnis, M., & Hofstein, A. (2008). The inquiry laboratory as a source for development of metacognitive skills. *International Journal of Science and Mathematics Education*, *6*(3), 601–627.

Klahr, D. (2000). *Exploring science: The cognition and development of discovery processes*. Cambridge: Massachusetts Institute of Technology (MIT).

Kohut, H. (1959). Introspection, empathy, and psychoanalysis: An examination of the relationship between mode of observation and theory. *Journal of the American Psychoanalytic Association*, *7* (3), 459–483.

Korpershoek, H., Kuyper, H., Bosker, R., & van der Werf, G. (2013). Students' preconceptions and perceptions of science-oriented studies. *International Journal of Science Education*, *35*(14), 2356–2375.

Kremer, K., Specht, C., Urhahne, D., & Mayer, J. (2014). The relationship in biology between the nature of science and scientific inquiry. *Journal of Biological Education*, *48*(1), 1–8.

Lamb, T. A., & Tschillard, R. (2003). *An underutilized design in applied research: The retrospective pretest*. Paper presented at the American Sociological Association. Atlanta, Georgia: National Conference on Applied Social Research.

Leach, J., Driver, R., Millar, R., & Scott, P. (1997). A study of progression in learning about 'the nature of science': Issues of conceptualisation and methodology. *International Journal of Science Education*, *19*(2), 147–166.

Lederman, N. G. (2007). Nature of science: Past, present, and future. In S. K. Abell & N. G. Lederman (Eds.), *Handbook of research on science education* (pp. 831–880). Mahwah, NJ: Lawrence Erlbaum Associates.

Lederman, N. G., Abd-El-Khalick, F., Bell, R. L., & Schwartz, R. S. (2002). Views of nature of science questionnaire: Toward valid and meaningful assessment of learners' conceptions of nature of science. *Journal of Research in Science Teaching*, *39*(6), 497–521.

Lengfelder, A., & Heller, K. A. (2002). German Olympiad studies: Findings from a retrospective evaluation and from in-depth interviews: Where have all the gifted females gone. *Journal of Research in Education*, *12*(1), 86–92.

Maxwell, J. A. (2004). Causal explanation, qualitative research, and scientific inquiry in education. *Educational Researcher*, *33*(2), 3–11.

Mayring, P. (2010). *Qualitative Inhaltsanalyse. Grundlagen und Techniken*. Weinheim: Beltz.

McCambridge, J., Witton, J., & Elbourne, D. R. (2014). Systematic review of the Hawthorne effect: New concepts are needed to study research participation effects. *Journal of Clinical Epidemiology*, *67*(3), 267–277.

McComas, W. F. (2011). Science fair. *The Science Teacher*, *78*(8), 34–38.

McComas, W. F., & Olson, J. K. (2002). The nature of science in international science education standards documents. In W. F. McComas (Ed.), *The nature of science in science education* (pp. 41–52). Dordrecht: Springer.

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.

Morrison, J. A., & Lederman, N. G. (2003). Science teachers' diagnosis and understanding of students' preconceptions. *Science Education*, *87*(6), 849–867.

National Research Council. (1996). *National science education standards*. Washington, DC: The National Academy Press.

National Research Council. (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas*. Washington, DC: The National Academy Press.

Novak, J. D. (2002). Meaningful learning: The essential factor for conceptual change in limited or inappropriate propositional hierarchies leading to empowerment of learners. *Science Education*, *86*(4), 548–571.

Paul, J., & Groß, J. (2015). Der naturwissenschaftliche Erkenntnisweg beim Wettbewerb *Jugend forscht. Praxis der Naturwissenschaften, Chemie in der Schule, Sonderheft Naturwissenschaftliche Erkenntnisgewinnung*, *6*(64), 43–45.

Petri, J., & Niedderer, H. (1998). A learning pathway in highschool level quantum atomic physics. *International Journal of Science Education*, *20*(9), 1075–1088.

Scharfenberg, F. J., & Bogner, F. X. (2011). A new two-step approach for hands-on teaching of gene technology: Effects on students' activities during experimentation in an outreach gene technology lab. *Research in Science Education*, *41*(4), 505–523.

Schauble, L., Klopfer, L. E., & Raghavan, K. (1991). Students' transition from an engineering model to a science model of experimentation. *Journal of Research in Science Teaching*, *28*(9), 859–882.
Schwartz, R. S., Lederman, N. G., & Crawford, B. A. (2004). Developing views of nature of science in an authentic context: An explicit approach to bridging the gap between nature of science and scientific inquiry. *Science Education*, *88*(4), 610–645.
Seidman, I. (2012). *Interviewing as qualitative research: A guide for researchers in education and the social sciences*. New York, NY: Teachers College Press.
Smith, C. L., Wiser, M., Anderson, C. W., & Krajcik, J. (2006). Implications of research on children's learning for standards and assessment: A proposed learning progression for matter and the atomic-molecular theory. *Measurement: Interdisciplinary Research & Perspective*, *4*(1–2), 1–98.
Sonnert, G., Sadler, P., & Michaels, M. (2013). Gender aspects of participation, support, and success in a state science fair. *School Science and Mathematics*, *113*(3), 135–143.
Stevens, S. Y., Delgado, C., & Krajcik, J. S. (2010). Developing a hypothetical multi-dimensional learning progression for the nature of matter. *Journal of Research in Science Teaching*, *47*(6), 687–715.
Strike, K. A., & Posner, G. J. (1992). A revisionist theory of conceptual change. In R. A. Duschl & R. J. Hamilton (Eds.), *Philosophy of science, cognitive psychology, and educational theory and practice* (pp. 147–176). Albany: State University of New York Press.
Sumrall, W., & Schillinger, D. (2004). Non-traditional characteristics of a successful science fair project. *Science Scope*, *27*(6), 20–24.
Urhahne, D., Ho, L. H., Parchmann, I., & Nick, S. (2012). Attempting to predict success in the qualifying round of the International Chemistry Olympiad. *High Ability Studies*, *23*(2), 167–182.
Vosniadou, S., & Brewer, W. F. (1992). Mental models of the earth: A study of conceptual change in childhood. *Cognitive Psychology*, *24*(4), 535–585.
Zabel, J., & Gropengießer, H. (2011). Learning progress in evolution theory: Climbing a ladder or roaming a landscape? *Journal of Biological Education*, *45*(3), 143–149.