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Trends in Practical Work in German Science Education

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By the 1970s a fundamental shift had taken place in German science education. This was a shift away from the learning of more-or-less isolated facts and facets in Biology, Chemistry, and Physics towards a restructuring of science teaching along the general principles of the respective science domains. The changes included also the addition of dimensions such as problem-based learning, understanding the basics of the Nature of Science, and engaging students in the methods of science. Since then, practical work has been solidly built into German science syllabi for each one of the separate teaching domains in school science. However, research evidence shows that practical work is still limited in many science classrooms. In many cases, hands-on work is only present as either teacher demonstrations or as cookbook-style recipe experiments for pupils. The shortcomings of such practice have also become evident in the TIMSS and PISA studies conducted since 1997. However, the outcomes published by PISA 2000 also initiated further change in Germany. For the first time ever, national science education standards were introduced for lower secondary science education. In 2004, these standards sharpened the focus of learning more prominently on how to practically carry out science tasks. The resulting reform led to research and development activity in different fields of innovation, among them science education practical work. This paper gives an account of the development of practical science work in German schools and it discusses the most prominent trends in practical science efforts in German secondary science education which have taken place in recent years.

Keywords: German secondary science education, standards, curriculum, practical work, syllabi

FROM THE ROOTS OF PRACTICAL WORK IN GERMAN SCIENCE EDUCATION TOWARDS CURRENT STANDARDS

The German educational system is quite complicated and confusing in some ways. Each of the 16 German Federal States ('Länder') operates an individually-defined system of school types, each with its own syllabi. On average, however, there are three basic levels of schooling in each State which roughly correspond to other school systems: (I) primary education in grades 1-4 (age range 6-10), (II) lower secondary education in grades 5-9 or 10 with respect to the school type (age range 10 to 15/16), and (III) upper secondary education in grades from 10 or 11 to 12 or 13 respectively (age range 15/16 and 18/19) (KMK, 2011). Primary and lower secondary education in Germany are compulsory up to age sixteen. In lower secondary education, different school types exist. Some German States have basic, middle and grammar schools running in parallel, which are attended by students based on their average grades and academic achievement in primary school. Other States distinguish between only two types of secondary schools. Yet others are currently attempting to integrate all of their pupils into a single type of lower secondary school, which will replace the older models.

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State of the literature

- Practical work is regarded an essential component of any science education in Germany since the 1970s. Since then it has been built into all the German science curricula.
- However, practical work still is limited in German science classrooms in respect to quality and quantity. Especially open ended or inquiry based experiments are rare.
- Since 2004, new national standards for science education in Germany emphasise the role of practical work more thoroughly by giving stronger focus towards the Nature of science and the way science "works".
- There is consensus throughout the literature, that innovation for the way practical work is done in German science classes is needed to fulfil the standards and for engaging more students into science courses.

Contribution of this paper to the literature

This paper reports recent trends in innovating German school science practical work like

- Increasing the chances for practical work through alternative equipment and materials,
- Using more flexible, more deeply-embedded methods in organizing practical work,
- Promoting open inquiry-learning in cooperative settings,
- Strengthening communication by combining practical work and cooperative learning,
- Assessing practical work alternatively, and
- Connecting formal and informal education due to out-of-school practical work.

Additionally, integrated comprehensive schools also exist in parallel to the three-tiered schooling system in more-or-less all German States at present. After lower secondary education, students can attend upper secondary schools. But, upper secondary education is not compulsory after the age of sixteen (for details see KMK, 2011).

The system is also very diverse with regard to science education but only at the lower secondary level. Primary science is taught as an integrated subject called Sachunterricht in all German Federal States. Sachunterricht combines topics from Biology, Chemistry and Physics together with issues from Technology, Geography, History and the social sciences. At the lower secondary level, science is taught as an integrated subject up to grades 6, 7 or 8, depending on which particular state and which type of school is being discussed. Even at present, each German State mandates its own syllabus for each school subject and each particular school type present within its borders. In upper secondary education, science is always split into the three distinct subjects of Biology, Chemistry, and Physics. Yet, course selection at the upper secondary level is normally mandatory for one (sometimes in single grades for two) of these subjects. Continuously studying two or all three subjects together is a facultative decision.

Just as German school systems and their syllabi are very diverse, so is the practice of teaching. Science teaching was established as a compulsory component of all German secondary schools during the 19th and early 20th Century. After World War II, science increasingly consolidated its position in the formal education sector. This consolidation took place in both former East and West Germany under different conditions. At any rate, science teaching in German schools by the 1950s was dominated by a lecture-hall style of lessons, which focused more-or-less exclusively on learning conceptual understanding (Häusler, 2002), as was the case in many other countries (Abrahams, 2011). Science education mainly stressed content rather than aiming its efforts at promoting general educational skills. Syllabi in science education centered on learning of facts and detached theories. Teaching practice was characterized by methods such as rote memorization (e.g., selected chemical elements and industrial applications in chemistry class) (Häusler, 2002). In secondary science, practical, hands-on work during this period was rare. In the few cases, where it occurred, it was often limited to lecturer demonstrations or students dutifully following prescribed manuals (Häusler, 2002), just as it was in many other countries (Lunetta, 1998; Abrahams, 2011; Lunetta, Hofstein & Clough, 2007).

Both the structure of science learning and the lacking emphasis on practical work in science education changed after the educational reform movement in the 1970s. A new subject was implemented into German primary schools in 1970. Sachunterricht replaced its predecessor, which had focused solely on the rote learning of the History and Geography of pupils' local environment and own country. From the 1970s onward, Sachunterricht was thought to introduce students to basic and scientifically sound elements of the natural sciences, technology, history and the social sciences. Sachunterricht was thought to provide pupils with an initial, science-based orientation towards their environment and give them a solid foundation for later studies. The pedagogies in both primary and secondary science during the 1970s also changed from rote memorization drills of facts towards more student-active learning in order to allow learners to discover essential aspects of the world around them on their own (Thomas, 2009). All the three science domains at the secondary level (Biology, Chemistry and Physics) also redefined their focus from learning detached facts towards achieving a more holistic understanding of the structure, principles and theories behind these related disciplines. More general educational objectives became the emphasis of syllabi throughout Germany. For example, skills including problem-solving and understanding how science is performed became the objectives of science teaching, including the role of practical work (Demuth, 1981; Häusler, 2002).

Secondary science was slower following the primary science movement towards pedagogies advocating more student-active, practical learning. Instead, the debate first emerged during the late 1970s and early 1980s, asking how schools should teach their students to understand exactly how science works (Becker & Hildebrandt, 2002). This development paralleled reform initiatives in the UK (Nuffield Project) and the United States ("Science – A process approach") (see Lazarowitz & Tamir, 1994; Abrahams, 2011). In Germany, however, several different proposals were made. Structured procedures were suggested for organizing students' learning processes. Most of the new approaches arising from the 1970s and 80s oriented themselves around problem-solving strategies. Examples of these include: inquiring teaching (Forschender Unterricht; Fries & Rosenberger, 1970), inquiring-scaffolding teaching (Forschend-entwickelnder Unterricht; Schmidkunz & Lindemann, 1992), and historically/problem-oriented teaching (Historisch-problemorientierter Unterricht; Jansen, Matuschek, Fickenfrerichs & Peper, 1986) (Becker & Hildebrandt, 2002).

Starting with Bruner (1961), all reform initiatives ranging from the 1970s and 1980s assigned practical work a much more prominent role in science teaching (e.g., Niedderer & von Aufschnaiter, 2008). This new role considered the potential, inherent in practical work in science, which reaches far beyond teacher demonstrations or pupils following cookbook recipes. The idea was to embed practical/hands-on student work into a structure of teaching-learning steps where experiments gain the important role of provoking or even answering learners' questions with regard to a specified problem (Häusler, 2002). Science teaching was, at this time, understood as much more than rote learning of the facts of science. It was now viewed as a key factor in understanding and learning science by actually performing processes of science. On the other hand, many skeptics remained doubtful about such a simple concept of performing more practical work to result in actively and intensely increasing students` conceptual understanding of the sciences (Abrahams, 2011). Nevertheless, all of these approaches pled for more learner experiments in class and moving away from teacher demonstrations towards – at least in part – practical work performed by the learners. This development has also had parallels in several other countries (Abrahams, 2011; Hofstein & Lunetta, 1982; Lazarowitz & Tamir, 1994; Lunetta et al., 2007; Solomon, 1980).

At any rate, the practice of secondary school science laboratory work has remained somewhat different in the German school system (Fischer et al., 2005) as well as in other countries (Hofstein & Lunetta, 2004; Hofstein, 2004; Lunetta et al., 2007). At the secondary level - if at all exists – the integration of practical work phases into the teaching-learning-sequences generally follows the phenomena of posing and answering questions within closely-defined limits. Unfortunately, students only rarely experience freedom in their thinking or in the latitude given them for their approaches to solving a given problem. In most cases practical work does not go beyond observing demonstrations carried out mainly by the teacher. In a recent survey among lower secondary/middle school Chemistry teachers in one of the German States, half of the teachers listed time, class sizes, or costs as a justification for not employing student practical work in their classrooms at all (Schaffer & Pfeifer, 2011). However, in the cases where pupil laboratory work was included, in most cases it was and remains little more than repeating cookbook recipe-style experimental activities firmly embedded in prescribed pathways (Ralle, 1993; Melle, Parchmann, & Sumfleth, 2004; Fischer et al., 2005).

Before the publication of the 1997 TIMSS and 2000 PISA studies, Germany largely expected to be evaluated as having an advanced, well-working educational system, including exemplary achievements in science teaching. The resulting shock after publication of the results was enormous. Germany had only a middling position among the participating OECD countries (Stanat et al., 2002). Active reform efforts to innovate science teaching began at all levels of German education. One of these reforms led to the establishment of national standards in science education for lower secondary schools in 2004. A curriculum change was made away from describing the content that should be taught to students. Instead defining the output which learners are expected to master, what they can actively perform and demonstrate became the center of focus. Whereas the older syllabi quite often were not more than just a list of keywords about teaching content, the new German standards defined competencies and skills that students should have achieved by the end of their compulsory schooling (KMK, 2004). Similar standards for primary education exist only for the subjects of German and Mathematics. The development of science education standards for upper secondary education is currently underway.

Table 1. The domain of 'knowledge generation' in the German national science education standards

	Level I	Level II	Level III
Knowledge generation	*… an ability to describe known inquiry methods and models and to conduct them with the help of a manual.*	*… an ability to select and apply suitable methods of inquiry and models in order to complete tasks of limited extent.*	*… an ability to reasonably select and adopt suitable methods of inquiry and appropriate models for the completion of complex tasks.*

The German national standards for lower secondary school science education selected a parallel structural approach for the three main science domains (KMK, 2004; Schecker & Parchmann, 2004). These standards define four different areas of competencies: (I) subject matter knowledge, (II) knowledge generation, (III) communication skills, and (IV) evaluation competency. With regard to practical work the second domain is the most important. 'Knowledge generation' includes learning about the 'use of experimental and other inquiry methods and models' (see table 1). This domain focuses on pupils explicitly learning how science functions and which strategies and methods are used in science to arrive at new knowledge. At the heart of this domain is learning about the Nature of Science itself, about the role of models and modeling in science and, of course, about the role of experiments.

Taking a more detailed look at the single standards within the domain 'knowledge generation', we recognize many items which necessarily demand that science lessons include practical work such as experiments. This is the case for all the three science school subjects. For example, the standards in Chemistry education state that:

"Students ….

Consider and develop questions answerable with chemical knowledge and/or inquiries, i.e. by chemical experiments.

Plan suitable inquiries for the testing of ideas and hypotheses.

Conduct qualitative and simple quantitative experimental inquiries and protocol them.

Observe safety and environmental aspects while performing experiments.

Create or research data using inquiry, i.e. through experiments.

Use suitable models (e.g., atomic models, the periodic system of the elements, etc.) to deal with chemical questions.

Demonstrate examples of connections between societal developments and the knowledge generated by Chemistry." (KMK, 2004)

These standards fall in line with current educational research evidence. There has been continuous support for inquiry-type and student-active practical work in the science classroom (Lunetta, 1998; Chinn & Malhotra 2002; Lunetta et al., 2007) in the science education literature since the 1970s. By introducing and implementing the German national standards, it was hoped that a shift away from the prevalent type of science teaching and towards more student-active, inquiry-driven science learning could be achieved at a level sufficient enough to gain support for sustainable implementation. Within this framework intense reforms in the area of practical work in German science education became commonplace.

Changes suggested by the various reform initiatives have focused on the implementation of new pedagogies which - among other aims – also want to include changes in practical, hands-on work. Many new curricula and teaching methods have been developed or even adopted from other fields of education research in an attempt to both embed practical work more deeply into the learning process and to focus on a broader field of skills. As far as practical work is concerned, however, very few ideas and case studies have been published beyond the German-language science teachers' journals. English-language references that evidence the feasibility and effects of differing teaching approaches from German science education are only rarely documented. A few examples of these with connection to innovating practical work are Markic and Eilks (2006), Ganser and Hammann (2009), and Rumann (2007).

The following sections give an overview of some of the recent reform trends of in practical work in German science education. The discussion will reflect upon their potential as far as evidence is available. Evidence in this case is based on a broader understanding than merely taking traditional research studies into account. Teachers' experiences as discussed in science teachers' journals and on teachers' conferences also form a highly-relevant corpus of knowledge for the profession of science teaching and learning. This knowledge covers the opposite half of the knowledge spectrum, which generally is not examined by or included in research-based evidence (McIntyre, 2005). McIntyre (2005) describes both sources of knowledge as beneficial for better understanding science teaching and learning practices. Sometimes teachers' practical knowledge - in this case on practical work - is the only information source available, since research-based evidence remains rare. Due to the basic paucity of English-language references to any developments in Germany, the current discussion will be mainly based on a review of German-language teachers' journals and books. Because of the varying language used within these many resources, only an illustrative selection of references will be given.

Where English references are available, they will be used instead. Most examples presented here stem from the field of Chemistry education, but also have many commonalities in Biology and Physics education.

Recent trends in innovating German school science practical work

Reform is an ongoing process in education. After the 1997 TIMSS and the 2000 PISA results were published, reform efforts in German science education got a much-needed shot in the arm for developing and implementing change. There were different movements within the overall framework of reform. In the following sub-sections, different innovation trends will be reviewed. Only those trends will be discussed which are directly related to innovating practical work in German science education.

Increasing the chances for practical work through alternative equipment and materials

One increasingly noticeable trend in German science teachers' journals in the last decades has been the development and implementation of more environmentally friendly and less cost-intensive techniques for carrying out practical work in the science classroom. Many experimental suggestions have been published, which allow for hands-on work employing less-toxic substances, using micro-scale approaches to reduce costs and waste products, and replacing traditional lab equipment with low-cost alternatives (e.g., Obendrauf, 2008; Poppe, Markic & Eilks, 2011; different examples from Germany are also provided in Hugerat, Schwarz & Livneh, 2006). The development of low-cost alternatives often focuses on experiments using common household or supermarket products (Schwedt, 2003) or on replacing expensive equipment and/or reagents with cheaper materials and products from either packaging waste or home improvement stores (Poppe et al., 2011).

Chemistry and Physics education have both developed new techniques. Examples of these include: performing classical experiments on a micro-scale with Petri-dishes as the basis for chemical reactions (Full, 1996), employing medical technology products like syringes to conduct micro-scale reactions or even biological experiments (von Borstel, 2009), and replacing standard physics lab equipment with apparatuses constructed from empty PET-bottles or tin cans (Wilke & Tronicke, 2007; 2008).

All of these techniques have found their way into teacher training courses and manuals for initial teacher training. Unfortunately, evidence confirming the range and intensity with which teachers are applying such newly developed ideas and materials remains rare and fragmentary. However, even school textbooks have begun to present alternative ways of carrying out experiments using low-cost and micro-scale techniques as a basis. This fact, of course, hopefully supports the underlying assumption that increasing numbers of teachers have both read about and started to use more low-cost alternatives to increase the amount of practical work in their classrooms today. This would also mean increased chances for pupils to actively experiment in science classrooms, at least in the quantitative sense.

Towards more flexible, more deeply-embedded methods in organizing practical work

In traditional German science classes, experiments mainly served as teacher-led demonstrations or limited student work following prescribed manuals. The latter experiments ("cookbook-recipe-style" experiments) were regularly conducted in parallel student group work. However, after the late 1990s a shift in the German educational scene could be observed with respect to implementing more flexible pedagogies for organizing classroom experiments. One of the first examples which took place parallel in all three science domains was the organization of hands-on, practical work for learners through the learning-at-stations mode (Eilks, 2002).

In a learning-at-stations classroom (Eilks, 2002), pupils are offered various numbers of workplaces (stations) where different types of activities teach various partial aspects of a topic. Students work on the different tasks at the stations in the sequence and time frame they select to piece their personal learning experience into a whole. It is the teacher's decision which stations are mandatory or optional, but students are then free to pick and choose from the offerings. This combination of compulsory and optional tasks also allows the teacher to control and expand the degree of openness in the lab work environment (differentiation). Inexperienced groups can be offered more guidance than veteran groups. More experienced groups can be allowed more freedom to decide for themselves than beginners (Bauer, 1997). Learning-at-stations allows teachers to combine different subtopics and activities which are thought to lead to networked knowledge. In an example based on biodiesel (Eilks 2000; 2002), students are required to examine differences in the viscosity and flammability of vegetable oil, rapeseed methylester (RME biodiesel) and conventional diesel fuel at two of the many stations. The change in the two products' properties is the reason behind the technical re-esterification process: viscosity and flammability. The importance of inquiring into both of the properties is explained at another station describing the work of a diesel engine. Yet another station covers model building of the molecules involved and allows learners to understand the changes in the substances' properties.

Two further stations deal with the technical process. At the first, students carry out the re-esterification process. The second explains the technical aspects of the physical plant. In the learning at stations pedagogy within this example, students are allowed to form a holistic and networked picture of biodiesel technology for both its experimental and theoretical side, then move towards its technical application. This is because the approach combines both practical and theoretical activities in an open learning environment. Within this setting participants can select the level of emphasis provided by the stations with respect to their personal interests and needs.

The learning-at-stations mode and related pedagogies quickly became a standard in teachers' repertoire of methods as described in science teachers' journals and handbooks. In any case, there is no measure of teaching time dedicated to these kinds of methods. But reports emerging from scientific teachers' journals and special issues for all three disciplines (Hepp, 1999; Gropengießer & Beuren, 2000; Stäudel, 2000) continue to yield an increasing number of examples within the teaching community supporting learning-at-stations. This might indicate an initial growth of this application within these fields.

Promoting open inquiry-learning in cooperative settings

Experiments play a central role in gaining new knowledge in science through integrated processes of constructing hypotheses, then planning and conducting experiments as well as observing and interpreting the data (Klahr, 2000; Hofstein & Lunetta, 1982). This is in line with the science education standards discussed above. It is also why inquiry-oriented practical work is important in teaching science (Lunetta et al., 2007). But application of inquiry-based learning in German science education has been rare up to now (Fischer et al., 2005). Therefore, different approaches are strongly suggested in order to strengthen the inquiry component at present.

One suggestion for strengthening inquiry-based learning in the science lab was embedding the practical performance of open experimental tasks in forms of cooperative learning. Cooperative learning as presented here serves as a setting for provoking the construction of meaning through communication about an experiment within a group of student learners. Cooperative learning ideas based on group investigation (Sharan & Sharan 1994) were suggested to offer chances for achieving better communication about experiments. Rumann (2007) suggested the use of interactive boxes covering experimental equipment together with a description of potential investigation. The material simply presents the problem and offers basic materials. Pupils are asked to develop their own hypotheses and to solve the problem in small groups. They are asked to find their own potential solution independently. Witteck and Eilks (2006) placed this idea of implementing group investigation into a more complex cooperative learning scenario called The Learning Company. A learning company is a didactically-constructed classroom structure, analogous to existing or "ideal" companies. Within the learning company all necessary steps of learning should be performed by pupils on their own, based on small learning groups and starting from open-ended tasks taken from practical work. These open tasks are framed within a fictional story of a company composed of different departments. Problems are presented so that no experimental direction is given. Instead, goal-oriented work orders from the boss, including a folder of information materials, a textbook and Internet resources, are provided to the groups of students. Groups of 4-5 students exhibiting differing scholastic achievement levels must solve the task without resorting to a restricted or prescribed pathway to the necessary answer. All work orders include a small story related to potential tasks which might occur in the fictional company, e.g., developing a new product or performing an analysis. These stories incite the learners to investigate the company and the potential products or services for which their team might be responsible. The groups receive their work orders, equipment and chemicals. Only the specific problem faced by the group and the materials which are available are listed on the work order, which is department-specific inside the company. The work orders do not contain explicit instructions for experimental procedures or apparatus construction. Pupils must plan and execute the experiments on their own initiative. Testing different examples of the learning company method (Witteck & Eilks, 2006; Witteck, Most, Kienast & Eilks, 2007; Beck, Witteck & Eilks, 2010) has revealed that the open-formatted, independent nature of the students' practical work forces learners to carefully discuss and exactly plan how they want to perform their experiments. But, the students are also guided by different sets of questions for learning on both theoretical backgound and everyday life applications. In the end phase, each department must present its problem, deliberations, experimental solutions, theoretical background and results to the company as a whole. This not only reflected upon the potential of their department, but also closely mirrors the functions in real firms of staff meetings, weekly reports, etc. The learning company approach clearly proved that it encouraged students to work actively, flexibly and with more autonomy and self-direction on the given experimental tasks.

There are many various approaches to this route of opening practical work up to inquiry-based and cooperative learning activities. All of the existing units which have been developed and tested up to now have evidenced positive effects on motivation and learning outcomes (Rumann, 2007; Beck et al., 2010). However, the breadth of their overall application has not been researched to date. To the present, application seems to be limited, as we might see from the limited discussion in science teachers' journals.

Strengthening communication by combining practical work and cooperative learning

The two above-mentioned trends focus primarily on strengthening group work activities to successfully carry out practical work. Whereas the learning-at-stations mode (Eilks, 2002) sometimes expands itself into an unstructured approach to students' group work, the interaction box (Rumann, 2007) or learning company approach (Witteck & Eilks, 2006) tend to more on initiating cooperative learning processes intrinsically. Yet each of these three methods doesn't automatically provoke quality cooperative learning as described in Johnson and Johnson (1999). Pedagogies resulting in high-quality cooperative learning, for example through individual accountability and positive interdependence, demand higher amounts of structuring. Methods like the jigsaw classroom (Aronson, Stephen, Blaney, & Sykes, 1978), Inside-Outside-Circle (Kagan, 1994), or Think-Pair-Share (Lyman, 1987) provide respective structure but haven't been applied in science education in Germany for a long time.

Yet science teachers' journals also document some efforts at change even here. All three science teaching domains have published special editions of teacher journals, which focused specifically on cooperative learning. Examples connecting practical work with structured cooperative learning techniques have become available, e.g., for the jigsaw classroom (Markic & Eilks, 2006), the Inside-Outside-Circle (Witteck, Most, Leerhoff & Eilks, 2004), and variations of Think-Pair-Share (Witteck & Eilks, 2005a).Two examples shall be outlined in brief as an illustration. Think-Pair-Share focuses its efforts on joint learning by an iterative comparison of individual solutions (Lyman, 1987). It aims at negotiating common ("better") solutions to a given task step-by-step. The students start individually. Then each pair of students compares their two solutions and negotiates a new joint draft in a second round. Examples for Chemistry have been produced by Witteck and Eilks (2005a) and for Physics by Hepp (2004). In connection with practical work, this method has been successfully coupled to jointly developing journals, protocolling experiments, and reaching interpretations of experimental results (Witteck & Eilks, 2005 a and b). In the interpretation employed by Witteck and Eilks (2005a), the whole class in the final phase selects the best solution or re-organizes parts of all the solutions into a joint product. The following evaluations revealed that learners evidenced increased levels of motivation, intense discussion and high on-task activity based on this method when writing up experiments or interpreting a given finding. Initial mistakes and weaknesses were recognized by the students and better versions gradually generated step-by-step. A second example is shown by the Inside-Outside-Circle developed by Kagan (1994). This method asks students in two rotating circles to first listen, then explain a newly-learned theory or specific information to each other in a sequence of different pairs. The technique uses the idea of reciprocal explanation, where each student must explain newly-acquired content to an expert as a control. The randomly-generated pairs of students formed as the inner and outer circles turn with respect to one another enable monitoring and control of the material. They also assure sufficient support for each individual learner on the basis of different, yet sequential explanations of the same material by differing partners. In the interpretation selected by Witteck et al. (2004), the learning group is divided into two groups of similar sizes. Both groups work out a specific issue, e.g., how to conduct a specific experiment or solve a given practical task. Both issues are related to each other, but do not overlap or build upon each other, e.g., how to measure and calculate density for solid or liquid substances respectively, or to work out the principle of two parallel electronic or electrochemical systems. The work is supported by appropriate materials where necessary and is organized as work in pairs of students or small groups. The central task for each group is to solve their own practical task and to develop an explanation about their topic. After these tasks the students form two circles, one inside the other. Each of the discussion pairs are composed of one expert from each group. Both 'experts' (inside and outside) present and explain their part of the topic to their partner. The 'non-experts' listen and make notes. Then one circle is rotated clockwise, the other counter-clockwise. New pairs of students are thus randomly generated and repeat their explanations of the topic presented to them in the first round. The opponent now listens, expands, and corrects. In this second phase the students have the chance to ask comprehension questions if the explanation they received in the first round was insufficient, since their new partners may be better able to explain the topic in a different way. After another rotation, each new pair is asked to look for parallels, differences, and any relationships between the two topics. From evaluations (e.g., Witteck et al., 2004), it has been recognized that this method also leads to high on-task discussion and provides a motivating framework for deeper contention with the experimental tasks.

Different examples have been published in German science teachers' journals and handbooks for all of these methods and many more. Many experience reports are available and a few research studies have shown the feasibility and motivating effects of more thoroughly embedding practical work into structured cooperative learning methods (e.g., Markic & Eilks, 2006; Witteck et al., 2007). Anyhow, any measures of the degree of implementation remain rare. However, a slowly growing body of papers in science teachers' journals and a growing recognition of the topic in teachers' guides accompanying science school textbooks seem to represent the first indicators of change.

Considering linguistic heterogeneity in practical work

To fully understand science instruction, pupils also need to be able to speak and understand the language spoken in the classroom (Rincke, 2011). As self-evident this claim might be, the question of linguistic ability has become a growing challenge in countries like Germany due to increasing rates of migration and multilingual pupils (Lee & Luykx, 2007). For example, one person out of five in Germany is currently either of foreign extraction or has a migration background. The 2000 PISA results showed great gaps in integration for students with migration backgrounds in Germany. This lack is considered to be one of the major problems in the German educational system in general, and in science teaching in particular (Stanat et al., 2002). German schools increasingly face the problem of dealing with rising numbers of students who don't speak German as their first language. Some students even start learning German only after entering kindergarten or primary school (Brandenburger, 2007). But linguistic deficits are not just a problem among students with migration backgrounds. Pupils coming from families with low socio-economic status quite often have language skills which are insufficiently developed. This is often also the case even among learners with a German family background (Hesse, 2008; Tajmel, 2010). In science education, the general malaise of language difficulties is aggravated by introducing the technical language of science. Technical language differs – sometimes quite radically - from everyday life language. Scientific sentences are often packed full of technical terms. Scientific texts are also frequently discontinuous and move between prosaic passages, graphical illustrations and formulae. Syntax is uncommon but nevertheless very important (Rincke, 2010; Sutton, 1992; Tajmel, 2011). Concerning practical, hands-on work in the classroom, linguistic problems can build a barrier for not only understanding both experimental instructions, but also the theory behind them. Experimental problems start with insufficient understanding of the technical terms for the equipment, materials or safety regulations. But problems also cover managing reports and protocols (Riebling & Bolte, 2008). The growing linguistic heterogeneity in German science classrooms has led to the development of many, specific pedagogies to try to reduce the problem (Busch & Ralle, 2011; Leisen, 2005; Markic, 2011).

Special tools for dealing with students` linguistic heterogeneity in science classes are currently under development (e.g., Leisen, 2006; Markic, 2011). Methods are under construction for supporting classes that are more-or-less strung out linguistically and extremely heterogeneous in their learning of science. Several examples can illustrate this. Dictionary catalogues can help pupils to protocol experiments, in the case that they have difficulties in the language. These catalogues cover explanations of terms/words add pictorial representations to them. Such dictionary catalogues can aid learners to better understand experimental instructions, to explain and describe potential experimental set-ups, and to manage the write-up of experiments afterwards. Even more structure is provided by tools giving help in both vocabulary and grammar. Such tools allow pupils to puzzle out full sentences based on a block-diagram, which provides different base forms and alternatives for each part of a sentence (noun, pronoun, verb, conjugation, adverb, and adjective). This guides students in correctly structuring and writing sentences. They can form sentences by simply selecting and combining the different parts from every language category, then adopting the words from their base forms to the proper grammatical form necessary for the sentence. Learners have the ability to check for different alternatives which both make sense with respect to the topic and sound good from the perspective of language use. In this sense, block-diagrams also contribute to the training of grammar and syntax. In any case, the explicit provision of words and phrases with their correct functions aids students in concentrating more of their energy and attention on the learning content, e.g., the experiment and observations, without being hindered by not being able to find the right words. A third form with the highest potential for aiding learners is the design-of-sentence table. These differ from simple block-diagrams, because the nouns, verbs, etc. in the design-of-sentence-table are already written in their inflected forms, so these "word hunks" can be used directly in a sentence. By the variation of different combinations of sentence parts and words, pupils are able to make different sentences. They can opt for those sentences that mostly accurate expresses their thoughts and sound best. This is of paramount importance in languages which decline not only the verb form, but also add endings and/or accents to plural nouns, adjectives, etc. or express various language functions using special spelling indicators (e.g., Leisen, 2010).

Initial evidence for applying such language-activating tools has recently become available (Markic, 2011). The evidence supports the claim that instruction and evaluation of practical work in linguistically heterogeneous classes is assisted by language-activating and supporting tools. This allows for the active inclusion of more students in practical and experimental tasks, including to contributing to better achievement. However, the use of language tools as a supporting measure for promoting lab work in classes that are linguistic heterogeneous is a relatively new field in German science education. Research regarding good practices and their effects in this area is, therefore, still quite thin. But various curriculum development projects and the accompanying research are currently under way in this field (Busch & Ralle, 2011; Markic, 2011; Streller & Bolte, 2011).

Assessing practical work alternatively

The German national standards focus on the ‘output’ of the learning process. This makes it necessary to evaluate the outcomes in order to check if the performance requirements posed by the standards are being met. It also requires tracking pupils’ learning progress during a teaching unit in order to adjust the teaching methods, if necessary. Up until now, however, most assessment tools used in German science education still are paper-and-pencil tests, which focus exclusively on conceptual understanding (di Fuccia & Ralle, 2006 & 2010). There is still a wide gap between the teaching objectives employed and the methods of assessment selected (Tamir, 1974; Bryce & Robertson, 1985). Based on the competencies outlined in the nationals standards concerning “knowledge generation”, assessment methods and diagnostic tools are necessary to define and describe these competencies and allow them to be assessed (Hofstein & Lunetta, 2004). Extant observations schemes (e.g., Hofstein & Lunetta, 2004) are extremely cumbersome and demanding, if they are to be applied by the teacher without an external examiner in the classroom (Tamir, 1989). This is why current research projects in German science education have begun a search for new diagnostic instruments, which both track learning progression during practical work, but are nevertheless applicable by teachers themselves with little to no outside support (di Fuccia & Ralle, 2006; 2010).

Examples of alternative diagnostic instruments for lab work include using lab reports in the form of photo-stories (Prechtl, 2011) and requiring student drawings of experimental setups (Schmidkunz, 2011) to actively diagnose the pupils’ understanding. Another approach developed by Sager and Ralle (2011) suggests using concept maps to diagnose pupils’ understanding of the connection between the experiments performed and the theory behind them. Schreiber, Theyßen and Schecker (2009) have also investigated to which extent computer-based, virtual experiments can be useful tools for diagnosing experimental competencies. Another verypractical approach towards diagnosis in the classroom which is less demanding and time-consuming was suggested by di Fuccia and Ralle (2006; 2010) and is based on modified experimental instructions. By modifying the instructional guides, two effects are intended: to make learners more deeply involved the experiment and to use the results of the pupils’ thinking as a diagnostic tool. One example of this is the use experimental instructions which provide a complete list of chemical substances and materials, but leave blanks in the description of how to conduct the experiment. Filling in the blanks before the experiment can be successfully carried out allows the teacher insights into whether the students are able to plan their own investigation or not. But such activities also challenge students’ thinking and problem-solving abilities. Students are often able to fill in the blanks. But certain errors also offer the teacher possibilities for assessing learners’ skills in conceptual understanding and planning experimental inquiries. They also give insight into obstacles in students’ problem-solving abilities or strategies. An even more consequent approach is to asking the participants to develop an experimental inquiry all by themselves, as presented in the above-mentioned learning company (Witteck & Eilks, 2006). In this way, open-ended problems can be presented to students to be solved as a written task. The learners need to devise ideas of exactly how the problem might be solved through an experiment. They must write down their individual proposals, which are then used to assess their problem-solving approach: developing a hypothesis, planning and conducting an experiment, then verification or falsification of the results. From evaluation and implementation case studies, evidence has shown that this method increases both learner attention and interest in the experiment, but also allows the teacher to better assess the essential components of students’ practical work skills. Another example is the diagnostic tool called the ‘necessity of prognosis’. This tool asks the students for a prognosis of their potential observations during an experiment and exactly why they expect them to come about (Reif & St. John, 1979). If used as a written assessment, this instrument aids teachers in assessing whether their students have understood the experiment and whether they were able to connect their practical activities to the theory underlying them.

Several such ideas for the alternative assessment of students’ competencies and abilities in practical work have developed and implemented in recent years. Nevertheless, evidence about their overall usage and the resulting effects is still quite thin. However, the few case studies where implementation was accompanied by testing offer some hope. The participating teachers reported that the use of such materials in their classrooms had given them an additional perspective, which they deemed to be important with respect to assessing their students' competencies in both inquiry and experimentation. Participating pupils also valued the new methods as helpful tools (di Fuccia & Ralle, 2006; 2010).

Connecting formal and informal education due to out-of-school practical work

One last trend to be discussed in this paper concerns the founding of out-of-school labs for informal practical work (Euler, 2002; Guderian & Priemer, 2008; Heinzerling & Latzel, 2002). Up to the present, more than 300 different labs existing outside of formal school education have been established for visits of either individual students or whole classes. These labs are operated by universities and research institutes, as well as in connection with museums and science centers. The range of topics covered is broad. Offers cover everything from traditional science research domains like Chemistry, Physics or Biology to modern fields of the Applied Sciences such as life sciences, material sciences, air and space engineering, and the physical foundations of modern ICT. Since the linkages of these topics are very diverse, their intentions also vary widely. Some labs intend to give visitors insights into authentic research in science and technology businesses. Others seek to provide students more personal experiences based on natural phenomena (Guderian, Priemer & Schön, 2006). At any rate, the driving force behind most of labs existing for informal practical work is the highly-publicized lack of student interest in science and engineering. Such labs were often founded in the hope that they could raise motivation and interest levels among young students regarding science and technology. They also want to promote a higher proportion of the younger generation which voluntarily chooses to enter into courses and careers in science and technology (Guderian & Priemer, 2008; Streller & Bolte, 2007).

Two examples can illustrate the work performed in student laboratories. The first is the one at Humboldt University in Berlin, where various topics are offered. Each topic was composed of a set of afternoon sessions about three hours in length. Learners are familiarized with one impressive phenomenon through an experiment, and then given time to inquire into the experiment in more depth. At the end of the session, each pupil presents the end results to the rest of the group and discusses the findings. Classes can visit either one single session or a series of three afternoons within the same topic. In the case of optics, the sessions are divided into "Light and shadow", "Angles and mirrors", and "Colors" (Guderian et al., 2006). This offer is thought to allow more practical work for the students then it is normally available in schools. It is viewed as an enhancement of formal education.

A second initiative from the University of Bremen directly links formal learning and the out-of-school lab (Marks et al., 2010). Fixed groups of students from specific schools opt for specific profiles in their upper secondary school program, which focus either on sustainable Chemistry or renewable energy sources. Pupils visit the lab throughout their three years of upper secondary education. There are two profiles connecting the out-of-school lab directly with science learning in regular school courses. In the first case Chemistry, Biology and Politics are covered, and in the second Physics, Chemistry and Politics. In both examples, lessons for the respective profiles are blocked into one weekday, where lessons are taught in a student lab at the university. Although all the lessons are still provided by teachers from the school, the teaching in the universiry is supported by the university staff. Students take advantage of the superior equipment and resources in the university labs and can rub elbows with authentic university researchers.

The body of research examining the effects of German out-of-school labs is still limited (Guderian & Priemer, 2008). Only single events or programs have been summatively evaluated. Also, the character of the lab visits is very diverse. Most of the labs offer only individual contact visits for school classes for a single morning or afternoon. Such models are of only limited potential for sustainably changing students' attitudes towards science or engineering. Other models encompass repeated visits to the out-of-school lab and are seen to have much stronger potential for positively influencing learners' attitudes towards science and technology (Guderian et al., 2006; Streller & Bolte, 2010). But, hard evidence in this area remains elusive and not many reliable, broad-based reports on experience are available. Negative side effects have also been frequently mentioned. Many critics point out that most out-of-school labs are not available area-wide, i.e. in rural versus urban environments. The offers on hand are also established through individual initiatives, based on available expertise and points of contact. This translates into the random availability of specific domains for individual schools. Out-of-school labs might also lead to individual teachers making the decision not to embed practical, hands-on work in their regular classes. A recent interview study revealed that such integration seems to be quite difficult, because many of the topics covered by out-of-school labs often do not fit in the school curriculum. Another factor is time-restrictions, which make a 'fit' between an already cluttered school schedule and university offerings almost impossible (Schmidt, di Fuccia, & Ralle, 2011). Up until now, it appears that the only projects showing positive and sustainable effects have been those which are based on long-term, reliable cooperation, including continuous visits of students in a specific environment (Guderian et al., 2006; Streller & Bolte, 2010)

CONCLUSIONS

Practical work in German science education undergoes continual change. Within science education curriculum development, new experimental techniques are constantly being developed, the objectives of practical work are being readjusted, and the pedagogy trends change towards more student activity, inquiry and cooperative learning. Many new experiments and curriculum materials have become available in recent years. It is safe to say that in many respects classroom practice started changing in many schools.

Yet as innovative some teachers and educators may be, change in the bigger picture of practice tends to be just as slow and unwieldy as ever (Fischer et al., 2005). We see the reason behind this to be the lack of systematic, broad-scale dissemination and implementation. There is a current need for more projects based on effective, experience-based and continuous professional development models as is done, for example, in collaborative or action research-based models of innovation (Parchmann et al., 2006; Eilks et al., 2010). As long as in-service teacher training in Germany is not compulsory - and in many cases organized through single contact events - innovation will remain plodding and less effective than it has the potential to be (Eilks & Markic, 2011).

All the trends discussed above have great potential for innovating science teaching towards more effective and broader styles of learning. This consideration is true from both a theoretical justification based on constructivist learning theory and from reported case study evidence and teacher experience observed in the classroom. The ground has been prepared for broad innovation in science education based on practical work. The challenge remaining before us is beginning the work on sustainable, broad-range implementation of such practices. This is a field which still suffers from too many deficiencies and insufficient financial and political support.

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