On the role of the experiment in science teaching and learning – Visions and the reality of instructional practice*

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Abstract. *The experiment is of key significance in science instruction – with regard to learning science content, processes and views of the nature of science. The state of research on the role of the experiment in science instruction is reviewed. Based on a brief sketch of the historical development of the role of the experiment in science teaching and learning since the 18th century the aims of experimentation in school and the state of empirical research on teaching and learning science by use of experiments are discussed. It is further analysed, whether the high expectation regarding the value of experimentation are justified. A particular emphasis will be given the fact that self-responsible experimentation is rather demanding for the students. Hence, there seem to be good reasons why this preferable variant of experimentation is so seldom set into practice.*

Keywords. Experiment, Lab Work, Student Self-Responsible Work, Teaching and Learning Science

A preliminary note on the terminology used

As various terms are used in the literature on what is called experiment in the present article some preliminary remarks are necessary. The term *experiment* is used in the meaning of scientific experiments on the one hand. But it is also stands for experiments used in science instruction for various purposes. A number of terms are also in use in the literature such as lab work or practical work. We further use the term *experimentation* throughout the article denoting the process of carrying out experiments.

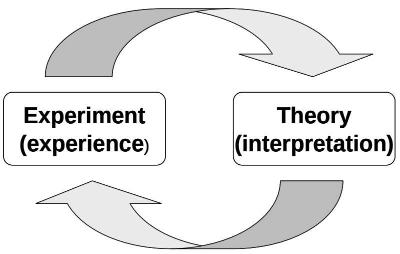

Fig. 1: On the relation of experiment and theory in scientific investigations

Introduction

The experiment plays a key role in teaching science. Science instruction without any experiment is hardly conceivable.[1] Clearly, the experiment is the key feature of science methods of investigating "nature". We deliberately do not use the singular *the* scientific method as it is not possible to identify such a method. There is a wide spectrum of epistemological and ontological views of the nature of science (NOS; [3]), that are linked to rather different strategies and methods of investigations [4].

In science the experiment is used to prove certain hypotheses by deliberate observation. Experimentation is always closely linked with theoretical modelling (Figure 1). Each experiment may only be carried out if it is based on a – maybe preliminary – hypothesis of the relations under inspection. In other words, the inquiry process is always based on an intimate interaction of experiment and theory – it is a *cyclical* process (cf. [5]).

This contemporary view of scientific inquiry is fundamentally different from the inductivist[2] view that formed in the end of the 18th century and that predominated in science and also in science education for a long time. The revolutionary changes of basic views in science (especially physics) that developed in the early 20th century step by step showed that this inductivist view had become obsolete [6,7].

The close interrelation of experiment and theory as outlined in figure 1 also holds for the role of experiments in science instruction. The

* This article draws on major ideas presented in [1].

[1] „*Science teaching must take place in the laboratory; about that at least there is no controversy. Science simply belongs there as naturally as cooking belongs in the kitchen and gardening in the garden*" ([2:13].

[2] *Inductivist* denotes the philosophy of science view based on inductivism.

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inductivist view has proven obsolete also for student inquiry processes when learning science. The “theory” (i.e. understanding of concepts and principles) does not develop solely or predominantly from the experiment. The genesis of understanding science is a cyclical process linking experiment and theory as well.

There are many variants of the use of experiments in instruction – ranging from the infamous “chalk & talk” strategy based on demonstrations at best to various forms of open inquiry providing students with opportunities of self-responsible activities. In principle, experiments allow to engage students in unique ways of self-responsible processes of inquiry such as observing, measuring, documenting of results, comparing and ordering, hypothesising and verifying, discussing, arguing and interpreting as well as investigating and communicating. This spectrum of inquiry processes is not only valid in science but also in various other domains. Learning to use these processes in science, however, provides a unique contribution to foster students’ general ability to carry out inquiries as the experiment in science allows intensive engagement with and deliberate manipulations of processes in nature and technology and not only mental manipulations.

In the following the role of the experiment in science instruction is investigated. A particular focus will be on the opportunities for student self-responsible work experiments in principle provide. The aims of experimentation will be discussed. But it is also investigated to what extend these aims may be set into practice in the reality of school science teaching. Finally, findings of empirical research on teaching and learning science are reviewed in order to find out whether the ambitious expectations regarding effects of self-resonsible experimentation are justified.

On the role of the experiment in science instruction – a historical account

A brief overview of the role of the experiment in science instruction from the 18th century to the present in German science education is given (for details see [7]). A particular emphasis will be given physics instruction as physics was the leading science until the early 20th century. Of course, the developments in other countries are somewhat or substantially different. The intention is to point out that the present – partly limited – state of the role of experiments in actual instructional practice (see below) may be better understood from a historical perspective.

It seems to be noteworthy, first, that the empiricist view linked with the above mentioned inductivist inquiry methods predominated science instruction in the 19th century and seems to be still – at least implicitly – influencing actual instructional practice. The inductivist method was the method of science inquiry and also the method to teach science.

Without any doubt, the instructional phases affiliated with this method (namely: problem – developing hypotheses – experimentation – analysis of the results – solving the problem – consequences for solving other problems) still plays a significant role in science instruction.

It is interesting to note that this method in the 19th century and in most of the 20th century as well was not explicitly taught in science instruction. It seems that it was taken for granted that instruction following the above phases would implicitly make students familiar with the method of science. It seems that this belief still plays a certain role in the actual practice of science instruction. At least – worldwide – demonstrations predominate and student experiments are integrated into primarily (strictly) teacher controlled instruction.

Without any doubt the past four decades saw significant changes – at least concerning philosophy of science, educational sciences and science education. On the one hand empiricist and positivist positions were questioned; on the other hand the predominating behaviourist view of teaching and learning was replaced by constructivist views [8]. Further, *science processes*, denoting the spectrum of science inquiry methods were established as a self-contained topic of science instruction [9], later also *views of the nature of science* (NOS: [10, 3]).

Investigating the intimate link of experimentation and theoretical modelling as outlined in figure 1 has become an important domain of science education research [11]. In contemporary approaches of scientific literacy [12] self-responsible inquiry is seen as an essential part. A large number of instructional approaches based on ideas of scientific literacy have been developed [13, 14]. In the actual standards for science instruction introduced in many countries worldwide [15] traditional science content (i.e. science concepts and principles) on the one hand and methods of scientific inquiry as well as views of the nature of science on the other hand are seen as equally important topics of instruction.

Briefly summarized, there is a development towards explicitly teaching issues *about* science (i.e., processes of scientific inquiry and views on the nature of science) as topics of science instruction in their own right.

Aims of experimentation in science teaching and learning

Various aims are affiliated with the experiment in science instruction – most of them are rather ambitious. Figure 2 presents key aims discussed in the literature.[3] It becomes apparent that an experiment allows illustrating the abstract science concepts and principles as well as science processes and views of the nature of science. Hodson [22] distinguishes three issues:

(a) learning science
(b) learning about science
(c) doing science.

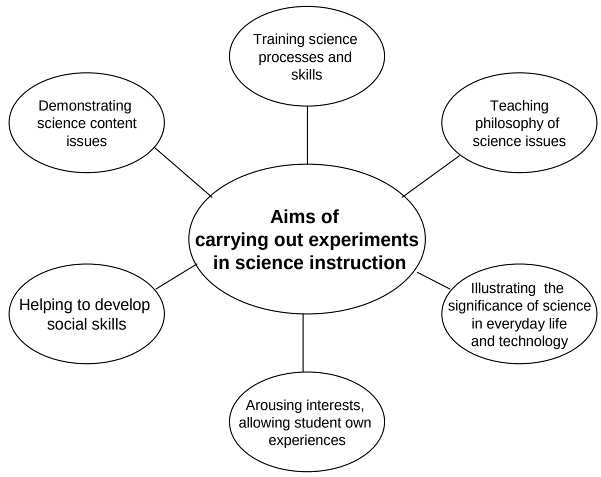

Figure 2: Various aims of experiments in science instruction [19]

Kircher, Girwidz, and Häußler [23:246] provide the following 14 issues:

(1) Illustrating a phenomenon
(2) Illustrating science concepts
(3) Provide basic experiences
(4) Provide experiences of science laws
(5) Prove theoretical predictions
(6) Investigate (find out about) student conceptions
(7) Make familiar with applications of science in technology and everyday contexts
(8) Incite student thinking
(9) Build up science ideas
(10) Prove science laws
(11) Make familiar with science processes
(12) Motivate and raise interests
(13) Provide sustainable impressions
(14) Allow to understand mile stones of human cultural heritage

In the history of science instruction in Germany briefly sketched above training of certain general "virtues" like prudence, accurateness, patience and responsibility also played a significant role. Still, these virtues are given a certain attention in science instruction.

Emphasis given the different aims of experimentation

Within the frame of a European project on the role of the experiment in science teaching and learning [24] a Delphi study on the significance given the various aims mentioned above was carried out. Some 400 science teachers at school and tertiary level from six European countries participated. They were asked to indicate the significance on a five point Likert scale. The following results appeared [25]:

- Linking theory and practice (4.1)
- Achieving skills to carry out experiments (3.7)
- Becoming familiar with methods of scientific inquiry (3.5)
- Motivation, social issues (2.5)
- Proving science knowledge gained (1.3)

It is noteworthy that the differences between the participants from the six countries are only marginal. The contribution to understand science theory is given higher significance than to understand science inquiry methods. It is surprising that achieving skills to carry out experiments is given quite high significance. This may at least partly be due to the fact that teachers at universities put a more significant emphasis of this issue as compared to school

[3] The literature on the various aims of the experiment in teaching and learning science is extensive. We especially draw on the following publications: [16, 17, 18, 19, 20, 21].

teachers who value motivational and social issues much higher than university teachers.

With regard to different kinds of experiments student experiments are quite highly rated by both kinds of teachers. This concerns all domains of science knowledge, i.e. concepts and principles as well as knowledge about science (i.e. on science processes and views about science). Interestingly, student experiments that follow a strict sequence of steps are seen as valuable to achieve experimental skills and to link theory and practice. However, they are viewed as much less valuable to support the development of social competences like fruitful cooperation in a group. Remarkable is also that demonstrations are seen as not useful to support the development of the students' personality. But they are viewed as valuable means to link practice and theory and to motivate students to learn science.

In a nutshell, these results reveal that despite certain differences between the teachers in schools and university there is a general agreement that experiments are significant means to foster learning of traditional science content, experimental skills and methods of science inquiry.

Studies on the practice of experimentation in science instruction

It is interesting that investigating the actual, "normal" practice of science instruction has not been a common research domain in science education. There are some data in the international literature on science instruction in action in various empirical studies with a somewhat different emphasis. In addition a video-study on teaching science in Australia, Czech Republic, Japan, The Netherlands, and the United States was carried out [26]. In Germany, large scale studies on the practice of physics instruction were conducted. Included were also samples from the German speaking part of Switzerland and the Czech Republic. At the moment a large scale video-based study to investigate the practice of physics 9^{th} grade instruction in Finland, Switzerland and Germany is running.[4] Results of the latter study are not available so far.

The experiment in German upper secondary physics instruction

As part of the German TIMSS (Third International Mathematics and Science Study; [27]) Baumert and Köller [28] asked students choosing physics courses in upper secondary level to provide information on the characteristics of their physics instruction. Experiments play a significant role, but it turned out that demonstration experiments predominate. Student experiments are rarely carried out. Further, a teacher dominated instructional style prevails. Usually the teacher carries out the demonstration experiment to develop a physics concept; students copy what the teacher writes on the blackboard. The teacher's instructional script includes the demonstration experiment, explanations by the teacher, and a strictly teacher controlled discussion within the class. This discussion may be characterized as "questioning-developing" strategy. The teacher asks a question, students who show up are invited to give their view. The teacher may respond to this answer or ask another student to provide his or her idea. In principle, this discourse may be fruitful if it is carried out in the spirit of a Galileian dialog. However, in German physics instruction it often seems to be a sort of ritual that is totally controlled by the teacher and does not use the potential for active student engagement.

Baumert and Köller [28: 296] conclude on the basis of the student responses in the TIMSS tests that instruction linking experiments and theory in such a way that students have a chance to be actively engaged in developing the science knowledge intended is particularly efficient.

A videostudy on physics grade 7 and 9 instruction in Germany and Switzerland

As part of a larger program of the German Science Foundation (DFG – Deutsche Forschungsgemeinschaft) a videostudy on the practice of German and Swiss grade 7 to 9 physics instruction was carried out[5] [29, 30, 31]. The pilot phase (2000 to 2002) included 13 teachers (Gymnasium and Middle Level School) from three of the 16 states Germany is composed

[4] http://www.unidue.de/fischer/dox/11.1432.4Njfs.H.De.php (June 2010)

[5] http://www.ipn.uni-kiel.de/projekte/video/videostu.htm (June 2010)

of. All teachers taught in schools participating in the nation wide quality development program SINUS ([32]. The sample of the second phase included 50 teachers from four German states. In addition a sample of 40 teachers in the German speaking part of Switzerland participated. This part of the study was directed by Peter Labudde [33, 34] and supported by the Swiss Science Foundation.

The focus of the studies was to identify key dominant features of German and Swiss physics instruction. In addition teachers' views about "good" physics instruction were investigated by a questionnaire. It was further intended to investigate relations between certain patterns of instruction and teachers' views on the one side and the development of student physics performance and their interests to learn physics on the other.

Video-documented physics instruction provide the major data of the studies. The teachers were asked to perform instruction as they normally do. In the first phase three lessons (45 minutes each) for two topics (namely electric circuit and force) were video-taped. In the second phase it was necessary to restrict to two subsequent lessons, either on optical devices or force.

Student questionnaires filled in before and after video-taping the lessons provide information on the development of student performance concerning the topics taught in the video-documented lessons and the development of interests. In addition after each video-documented lesson students were asked to provide their views about instruction documented. Teachers filled in a questionnaire before the video-documented lessons on a set of general views and beliefs. Further, some 40% of the teachers were interviewed after the last lesson video-documented. The intentions of these interviews was to identify teachers' views about good physics instruction on the one hand and their views about their instruction video-documented.

Instruction was documented by two digital cameras. One camera targeted the teacher, the other the whole class. A particularly designed software (Videograph[6] – [35]) allowed to code the videos in sequences of 10 seconds. Major coding systems comprise:

- Basic forms of instructional methods (whole class activities, still work, group work)
- Phases of instruction (repetition, learning of new content, experimentation)
- Support of learning during whole class activities
- Role of experiments

The results concerning the role of the experiment will be briefly summarized in the following (for details see [19, 36]). It is essential to point out first, that instruction in general is rather teacher dominated. Only 17% of instructional time is used for student activities. However, there are substantial differences between the teachers [31]. Time used for whole class activities varies between 19% and 100%. These activities are usually rather strictly teacher controlled. The above mentioned questioning-developing discourse prevails. Usually there is an interaction between the teacher and single students. It rarely happens, for instance, that a teacher asks another student to comment on what the classmate said before.

Experiments play a significant role in the lessons. Some 71% of the lesson time is governed by the experiment. It is particularly remarkable that much time is used to discuss the results.

- Introduction into the experiment (12%)
- Carrying out the experiment (21%)
- Discussion of the results and findings (35%)

For student experiments some 11% for demonstrations some 7% of instructional time is used. There are, however, substantial differences between the teachers. Students only have marginal opportunities to plan experiments, to carry them out and to draw conclusions themselves.

Usually the experiment is employed when a new content issue is developed. In some 70% of the documented cases the experiment is used to illustrate a phenomenon, only in some 20% to illustrate a concept or a law. To prove a hypothesis an experiment is rather rarely used.

The results provided by the video-study very much remind of the above use of the experiment in upper secondary level. The good message is that physics instruction in German and Swiss lower secondary physics instruction may not be

[6] http://www.ipn.uni-kiel.de/aktuell/videograph/htmStart.htm (June 2010)

indicated by “chalk & talk”. On the contrary, the experiment plays a rather significant role as more than 70% of the teaching time is linked to experiments. It is interesting that the actual time the experiments are carried out is not very impressive. The data point out that the discussion of the results of experiments is the essential part of physics instruction. It seems that these findings are in accordance with the view of Baumert, Klieme and Bos [37] drawing on German TIMSS data that it is necessary to “intelligently” integrate the experiment in physics instruction. The introduction phase is essential in order to allow students to understand in which context the experiment to be carried out is embedded. The discussion of the results – which is given much time – is of key significance as well.

Taking into account that the belief is quite common that student experiments result in better learning and better development of interests (see below) it seems to be remarkable that the data of the video-study showed that there is no significant advantage of student experiments with regard to better achievement. These results are in accordance with many other studies on the effects of student experiments (see below). Based on the video-data available, often not enough time is spent by the teacher to summarize and analyse the findings of the student experiments. It is quite likely, that this is a major reason for limited development of achievement in student experiments.

Student experiments as observed in the videos are primarily strongly teacher controlled. There are only a few cases where students are given the opportunity to plan an experiment und to carry it out by themselves. In general, students rarely have an opportunity for self-responsible activities.

The data of the first phase of the video-study provide information on the relation between the aims these 13 teachers have with regard to the role of experiments und their actual use of experiments in class ([38, 39]. All teachers claimed that student experiments are rather valuable. In the lessons of two of these teachers, however, no student experiment was carried out. All teachers argued in the interview that they would love to use more student experiments – however they often cannot find the time to do that as student experiments are rather time consuming and the necessary equipment is often missing.

With regard to the above discussed restriction of “traditional” science instruction to concepts and principles, results of the first phase of the video-study seem to be essential. An analysis of the videos from a constructivist perspective [40, 41] revealed that teacher in class almost never mentioned issue regarding science inquiry processes or the nature of science. The teacher interview showed that most teachers were not well familiar with neither of the two issues ([38, 41]; for similar findings see [42].

On the role of the experiment in science instructional practice – a summary

Most results on the role of the experiment in instructional practice are valid for German physics instruction. The results for the German speaking part of Switzerland are basically rather similar. However, the student experiment seems to be more often used in Swiss schools. But also here most of these experiments are teacher controlled.

Fraefel ([43] carried out a small scale video-based study on science instruction in the German speaking part of Switzerland. In this study a basically similar picture occurred as in the above physics video-studies in Germany and Switzerland.

It seems to be remarkable that in the reviews on lab work in the international literature [17, 18, 21, 22, 44] as well as in the TIMSS video-study on science instruction in five countries [25] a similar situation becomes apparent.[7] Hence, it appears that the limited use of the experiment as revealed in the video-studies in Germany and Switzerland is characteristic for the majority of schools also in international perspective.

In a review on the use of contemporary constructivist oriented approaches in science teaching Duit, Treagust and Widodo ([45: 638f] come to the conclusion that major ideas of student oriented conceptual change approaches are rarely to be observed in actual classrooms. In other words, there seem to be limited chances for student self-responsible activities in science classes. Students rarely have the chance to plan

[7] *„Many of the activities outlined for students in laboratory guides continue to offer „cook-book“ lists of tasks for students to follow ritualistically. They do not engage students in thinking about the larger purpose of their investigation and the sequence of tasks they need to pursue to achieve those ends”* ([18:47].

an experiment, to develop and prove hypothesis. The wide spectrum of ambitious and challenging self-responsible activities student experiments in principle allow seems to be used insufficiently in instruction practice.[8]

Empirical research on self-responsible experimentation

In the following we will provide a summary of studies on the effects of teaching and learning science with the aid of experiments. A particular emphasis will be given studies on variants of self-responsible student experiments, i.e. on the use of the experiment in settings that allow the students to follow their own ideas in planning, carrying out the experiment and summarizing the results.

The overview is based on the reviews available. Formal meta-analyses are not available so far. The authors of the reviews usually point out that it is rather difficult to come to clear conclusions concerning certain cognitive or affective effects of the many variants of experiments used in science instruction as many studies available are somewhat deficient concerning their methodological design ([17:9,18:29]. The following attempts to summarize findings are preliminary due to these deficiencies.

Effects of student experiments

As mentioned already manifold effects are expected from student experiments. These expectations usually are not backed up by empirical research. Student experiments per se do not result in better science performance (i.e, in better understanding of science concepts and principles), they do not incite a more pleasing development of interests in science and learning to understand science, and they do not support understanding science inquiry methods and views of the nature of science. It very much depends on how these experiments are staged. It is essential to provide learning opportunities that sustainably support learning [17, 18, 20, 22].

[8] Lyons [46] investigated students' views of their science instruction in Sweden, the United Kingdom and Australia. Surprising similarities occurred. In all countries most students are of the opinion that their teachers would just pass knowledge to them. Students accordingly are of the opinion that instruction is rather closely guided by the teacher and that there are only a few opportunities for self-responsible work.

It is noteworthy that quite a substantial number of studies are available on the three issue listed in the heading of this paragraph. However, only a few studies investigate the development of skills to properly carry out experiments. Even less frequent are studies on the development of the above virtues like prudence, accurateness, patience and responsibility.

Quite frequently, the following proverb is employed to back up the belief that student experiments are superior: "*I hear and I forget, I see and I remember, I do and I understand*". Harlen [17:9] points out that there is no empirical evidence for this belief in studies on teaching and learning science by experiments. Instruction in which student experiments play a significant role does not necessarily lead to better science performance as compared to instruction in which students do not carry out experiments ([17:17, 18:31].

In a study on learning the basic laws of the simple electric circuit, for instance, van den Berg, Katu and Lunetta [47] showed that only "hands on activities" usually did not result in more elaborate student understanding. Carefully designed activities to question student pre-instructional conceptions and hence to incite cognitive conflicts proved to be essential.

White and Gunstone [48] come to the conclusion that meta-cognitive learning experiences play a central role in facilitating understanding. They claim that the manipulation of ideas is more important than manipulation of the materials used in the experiment. In other words, "*hands on*" is less important as compared to "*minds on*".

Hopf [20] embedded student experiments into authentic contexts and allowed problem based student work. Student pre-instructional conceptions were deliberately activated. The basic idea was that students should be given the chance to experience physics as interesting and to further develop their self-concept regarding learning physics. Teachers were of the opinion that this variant of student experiments is a valuable enrichment of the repertoire of instructional methods. It further turned out that embedding into contexts may be result in better cognitive learning outcomes as other research also has shown [49, 50]. However, it also became obvious that a better understanding of science content only occurred if students actually used the potential of the problem-based experiments embedded in authentic contexts. In addition the improvement of affective variables like student interests and self-concepts turned out to be somewhat minor [20: 228].

Hofstein and Lunetta ([18: 31f, 44] point to another important issue. When carrying out experiments often so much time is needed to handle technical and manipulative details that only little time is left for the development of science understanding.[9] Woolnough [51] claims, that for this reason the potential of experiments is often not well used.

As mentioned it is a widely hold view that student experiments lead to better student interests. The manifold results available do not necessarily back up this view [17: 7]. Hodson [52] found that some 50% of his students appreciated student experiments but that this was not at all the case for the other 50%. It further became obvious that many students were not sure what they were actually doing during the experiment and what to do if something went wrong.[10] Labudde [53: 150ff] reports that his female Swiss upper secondary level students preferred demonstration experiments. There are also findings in the above video-study in Germany that point into the same direction. Many female students preferred demonstrations – especially when they were carried out by other students. In summarizing, it seems to be justified to state that student experiments may lead to some improvement of affective variables. Hopf ([20], for instance, reports small increases. However, such effects only occur, if the experiments are appropriately staged.

Regarding the development of understanding science inquiry methods (the science processes) and views of the nature of science empirical studies point into two directions. There is clear evidence that the strictly teacher controlled student experiment (including primarily "cook-book activities") is counterproductive ([17:1, 22:95]. Such experiments result in a narrow view *about* science. Again, the development of contemporary epistemological views does not result quasi automatically from the practice of carrying out experiments – even if this practice is deliberately informed by the actual state. It is necessary to carefully initiate and further support such developments. It has to be taken into account that students have serious problems to understand and learn the ambitious science inquiry methods and their interplay [11, 54, 55, 56, 57].

Cooperative work

Student experiments provide powerful opportunities for intense student cooperation – however this needs to be deliberately supported. It also has to be carefully taken into account that the student work is focussed on dealing with the task chosen or given. Alton-Lee, Nuthall and Patrick [58], for instance, observed that most of the discourse in their groups was task related. However, most of the talk dealt with organizational and not with conceptual issues.[11] According to a review provided by Rumann [59], cooperative work seems to be a rather valuable method to support cognitive and affective development. However, the gains are generally somewhat small, i.e. in the same magnitude as the gain achieved by Hopf [20] in his above sketched approach [59: 110].

Students view experiments in their own way

According to constructivist epistemological views of teaching and learning students make their own sense of everything presented to them in science instruction, hence also of the experiments they carry out themselves or presented to them [60]. Lunetta [61: 250f] summarizes a number of studies in stating that students who carry out experiments usually are oriented at other goals than intended by the teacher. Many students, for instance, view "follow the instructions" and "find the right answer" as the major goals of their work.

Tasker [62] asked students who carried out experiments what they were doing and why they were doing that. It turned out that for strictly teacher controlled "cook book" like activities students did not really know what they did and what the purpose of the experiment was. They further had only vague ideas on the aim of the experiment. Champagne, Gunstone and Klopfer [63] as well as Chang and Lederman [64]

[9] *"In summary, data gathered in many countries has continued to suggest that teachers spend large portions of laboratory time in managerial functions, not in soliciting and probing ideas or in teaching that challenges students' ideas, encouraging them to consider and test alternative hypotheses and explanations"*([18: 44].

[10] These findings point to an issue more fully discussed below: To carry out student experiments is cognitively rather demanding for students.

[11] Cf. the findings provided above that during experimentation (in student and demonstration experiments) much time is used for the management and technical details.

reported similar findings. An additional problem is due to the fact that students' conceptions of the phenomenon investigated often are not in accordance with the science view [65]. As a result several severe problems occur. Student observations, namely, are substantially influenced by these conceptions. Observations are not objective but at least partly determined by the expectations suggested by the conceptions hold. Hence, students tend to observe something that is different from what the teacher intended [66].

Students' dealing with complexity

Self-guided experimentation is rather demanding for the students – even for strictly teacher controlled experiments. It is necessary to understand the written (or orally given) instruction, to handle the materials properly, to measure, to put down results, to process and interpret the data gained, and to cooperate with others. In addition it has to be taken into account, as outlined previously, that students make their own sense of the experiments. Many students have severe difficulties to deal with this complexity and tend to rather superficial kinds of experimentation. Johnstone and Wham ([67] illustrate how students tend to react to these demands by choosing strategies that have nothing to do with what the teacher intended:

(1) Adopt a recipe approach
(2) Following the steps in the instruction manual mechanically
(3) Focus on one aspect of the experiment in which they are busy getting nowhere
(4) Become helpers or assistants to a group organizing and run by others

Open inquiry

Variants of "open" experimentation allowing inquiry are particularly demanding for students. Metz [68] argues that students may loose control of what they are doing and hence are overstrained. In a video-based learning-process study Duit, Roth, Komorek and Wilbers [69], for instance, investigated how students find out the reason for the strange behaviour of a chaotic pendulum themselves. There are a number of cases documented in the data that students constructed a view being not in accordance with the physics explanation. It also becomes obvious how difficult it is to persuade and convince the students that the explanation they constructed, and is hence laden with personal significance is not acceptable from the physics point of view.[12]

Summary and Discussion

The experiment plays a truly significant role in science instruction – in the literature on the role of the experiment and in instructional practice as well. It is rather fortunate that there is no reason at all to blame the practice of experimentation in schools as "talk & chalk". However, the opportunities provided for an active engagement of students in experimentation is still rather limited. Student self-guided experiments are very seldom to observe in instructional practice – all over the world. Even if the student experiment plays a significant role (as, for instance, in the UK), variants of experiments predominate where the term "cookbook experiment" is well taken. Opportunities for students to plan experiments, carry them out and process the results themselves are not frequent. Hence, opportunities to become familiar with key methods of scientific inquiry are only seldom offered.

It seems, in general, that the practice of science instruction is still significantly focussed on teaching and learning science concepts and principles and neglecting competencies providing insight into science inquiry and views of the nature of science – which are given a major emphasis in more recent standards of science education. As a result science instruction usually seems to provide a somewhat limited scientific literacy.

However, the results on the role of the experiment in teaching and learning science indicate that the certain "resistance" of instructional practice to provide the appropriate learning opportunities to achieve "full" scientific literacy is based on good reasons. As more fully outlined above, the ambitious aims linked with targeting scientific literacy are rather demanding to achieve. Students have serious problems to deal with these ambitious demands. Also teachers usually have severe problems to set the ambitious goals into practice [18: 39].

In a nutshell, there is the following situation. The well founded "visions" on the role and aims of experimentation in science instruction and the reality of teaching-learning-processes in normal

[12] The learning processes observed often turned out to be "random" when students included a spontaneous idea into the discourse [70].

practice do not fit well. Self-guided experimentation, for instance, may only be learned in long lasting series of attempts step by step.

Results of research on instructional quality, in general, show that there are no simple recipes for improving achievement and developing affective variables [71]. Student experiments, for instance, per se do not lead to better cognitive learning and a more pleasing development of affective variables. Further, deep understanding of science inquiry and views of the nature of science do not simply result from student self-responsible experiments. The many potential effects of experimentation claimed when the use of experiments is justified may only be set into practice by sustainably supporting the necessary teaching and learning processes.

Taking into account the scripts predominating the practice of science instruction which are based on teachers' personal views and what research has to offer to improve the situation the following dilemma becomes apparent. On the one hand empirical research on teaching and learning science provides empirical findings on how instruction may be improved. On the other hand, research on teachers' views and implicit theories of "good" instruction show that most teachers will have severe problems to set the changes suggested by research into practice. In other words, substantial research on professionalization of teachers to enact a more efficient use of experiments is needed.

A final remark concerns the title of the present conference: HANDS-ON SCIENCE. As briefly mentioned, *hands-on* needs to include *minds-on*. That means, diligently and beautifully designed experiments do not necessarily result into the outcomes expected – they need to be staged adequately in such a way that *hands & minds on* actually may occur.

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