Open Access Repository
www.ssoar.info

Promoting pre-experimental activities in high-school chemistry: focusing on the role of students' epistemic questions

Neber, Heinz

Postprint / Postprint
Zeitschriftenartikel / journal article

Zur Verfügung gestellt in Kooperation mit / provided in cooperation with:
www.peerproject.eu

Empfohlene Zitierung / Suggested Citation:
Neber, H. (2008). Promoting pre-experimental activities in high-school chemistry: focusing on the role of students' epistemic questions. *International Journal of Science Education*, *30*(13), 1801-1821. https://doi.org/10.1080/09500690701579546

Nutzungsbedingungen:
Dieser Text wird unter dem "PEER Licence Agreement zur Verfügung" gestellt. Nähere Auskünfte zum PEER-Projekt finden Sie hier: http://www.peerproject.eu Gewährt wird ein nicht exklusives, nicht übertragbares, persönliches und beschränktes Recht auf Nutzung dieses Dokuments. Dieses Dokument ist ausschließlich für den persönlichen, nicht-kommerziellen Gebrauch bestimmt. Auf sämtlichen Kopien dieses Dokuments müssen alle Urheberrechtshinweise und sonstigen Hinweise auf gesetzlichen Schutz beibehalten werden. Sie dürfen dieses Dokument nicht in irgendeiner Weise abändern, noch dürfen Sie dieses Dokument für öffentliche oder kommerzielle Zwecke vervielfältigen, öffentlich ausstellen, aufführen, vertreiben oder anderweitig nutzen.
Mit der Verwendung dieses Dokuments erkennen Sie die Nutzungsbedingungen an.

Terms of use:
This document is made available under the "PEER Licence Agreement ". For more Information regarding the PEER-project see: http://www.peerproject.eu This document is solely intended for your personal, non-commercial use.All of the copies of this documents must retain all copyright information and other information regarding legal protection. You are not allowed to alter this document in any way, to copy it for public or commercial purposes, to exhibit the document in public, to perform, distribute or otherwise use the document in public.
By using this particular document, you accept the above-stated conditions of use.

gesis
Leibniz-Institut
für Sozialwissenschaften

Mitglied der
Leibniz-Gemeinschaft

Diese Version ist zitierbar unter / This version is citable under:
https://nbn-resolving.org/urn:nbn:de:0168-ssoar-132494

Promoting pre-experimental activities in high-school chemistry: focusing on the role of students' epistemic questions

Journal:	*International Journal of Science Education*
Manuscript ID:	TSED-2007-0132
Manuscript Type:	Research Paper
Keywords:	chemistry education, questioning, laboratory work, quantitative research, experimental study
Keywords (user):	

Promoting pre-experimental activities in high-school chemistry: focusing on the role of students' epistemic questions

In high-school chemistry the pre-experimental phase of inquiry cycles often remains neglected. According to a procedural model, which is described in the text, this phase begins with an observation which stimulates students' prior factual knowledge, the formulation of a research question for further elaboration (epistemic questions), the anticipation of a hypothetical answer, and the planning of experimental steps for deciding on the hypothetical answer. These activities were explicitely prescribed in an experimental group of 28 tenth-graders. Raising the quality of students' epistemic research questions by providing structured help was a special focus of the intervention. Hypothesized motivational and cognitive effects were measured and compared to a group of 25 students (control group) who engaged in non-structured pre-experimental activities. The intervention provided to the experimental group resulted in stronger preferences for a more open and non-recipe type of experimentation, in more intense cognitive activities (thoughts) and, most importantly, in increased skills for formulating causal epistemic questions. Supporting such procedural skills in classrooms may contribute to transforming labwork into intentional activities and students into active learners by helping them focus on further elaborating their knowledge.

Introduction

Lab-based science education has already been in demand for more than forty years. Currently, the standards-based reform movement renews the demand for a break with exclusively receptive forms of instructional practices. Accordingly, knowledge in science should be constructed by hands-on activities that are based on cognitive minds-on processes like hypothesizing or searching the mind for causal explanations of scientific phenomena.

Various objectives are involved with these claims for an inquiring kind of knowledge acquisition. Lunetta (1998) ascertained that early versions of inquiry mainly focused on the acquisition of procedural knowledge in terms of science process skills. In contrast, and above all, current developments aim at the acquisition of domain specific conceptual knowledge (Hofstein & Lunetta, 2004). Besides such cognitive effects, motivational objectives should be attained by experimenting in education. Lederman (2004) makes clear that raising the level of science-related motivation represents an important goal of standards-based reform with its emphasis on hands-on activities. MacIver, Young and Washburn (2002) found that such activities might be good for motivational expectations and science-related value conceptions of middle-grade students. Altogether, it turns out that multiple cognitive and motivational objectives are connected with student experimenting and inquiry in science education (Pedrosa de Jesus, Teixeira-Dias & Watts, 2003). Correspondingly, teachers in several European countries expect multiple positive effects from labwork in science (Séré, 2002).

However, these objectives and expectations will not be attained only by increasing the frequency of students' experiments in instruction. According to the summarizing review of Lazarowitz and Tamir (1994), it was repeatedly observed that actual experimenting in school-labs often has very limited effects on the acquisition of procedural skills, on conceptual knowledge, and even on motivation to engage in experimenting. On the one hand, such discrepancies between objectives and reality may be due to the instructional design of labwork as a learning environment. On the other hand, they may be caused by missing individual prerequisites required for investigations by the students.

As a learning environment, labwork is not implemented in a uniform way but in quite various forms. According to Lunetta (1998), these variations may be characterized in terms of two aspects. Firstly, the extent of external guidance and control of the experimental activities considerably varies. Open forms which offer a wide range of personal/individual decisions to the students may be distinguished from very structured forms with detailed prescriptions of students' activities. Secondly, besides the degree of structuredness, the spectrum of activities that is required from students in labwork differs. Activities in the lab may be strongly restricted, e. g. only setting up the experiment, or the lab activities may cover almost all phases of inquiry cycles.

Insufficient learning effects that do not meet the intended objectives of students' experimenting may be related to these two aspects of actual labwork in science education. Firstly, limitations may be due to the high degree of pre-structuring of students' activities in the lab. This is a characteristic of the most popular 'expository' style of instruction in the lab (Domin, 1999). Accordingly, McRobbie and Thomas (2001) found that chemistry labwork in Australian high schools mostly consisted in prescribed routine activities. Students were rarely offered opportunities for their own initiatives. In this way, experimenting is becoming a recipe-like step-by-step prescription, thus preventing crucial high-level minds-on activities of the students. As a consequence, cognitive processes run off only at lower taxonomic levels.

Secondly, quite often labwork is realized as a very restricted spectrum of activities. By contrast, Tobin (1990) claims that cognitively and motivationally effective labwork in science should begin with tasks from which problems emerge, and that run as a complete cycle of problem solving processes. According to Lunetta (1998), a sequence of four general phases should be considered: In the planning-and-design phase, problems emerge, research questions are formulated, hypotheses are formed, expected results are predicted and further experimental activities are designed. In the performance phase, planned activities are carried out, and data are observed and recorded. In the analysis-and – interpretation phase, the data are interpreted, generalized conclusions are drawn, and further research questions are formulated. Finally, in the application phase, the acquired conceptual and procedural knowledge is applied to find solutions for new research questions. By collapsing the last two phases, a three-step sequence results that is termed as the “pre-experimental, experimental, and post-experimental phases of labwork” (Doran, Lawrenz & Helgeson, 1994).

In science education some of these phases are neglected. Above all, this applies to pre-experimental activities. Tobin and Capie (1982) found that in labwork only about three percent of the lab-related time is applied to developing research questions for experiments. Neber and Heumann-Ruprecht (2006) confirmed this result by asking 60 chemistry teachers and more than 200 high-school students on how time is used in school-based chemistry labwork.

Yet, in implementing the pre-experimental phase of inquiry-oriented labwork in a more complete and open way, it may be the case that students will have available to them only rather insufficiently developed skills for planning and conducting own investigations. According to Carey, Evans, Honda, Jay and Unger (1989), eleven year-old pupils are often unable to pursue experimental tasks by elaborating explicit research questions on their own and planning their experimental manipulations in advance. Schauble, Glaser, Raghavan and Reiner (1991) found similar deficits with undergraduate physics students having poor learning gains in computer-based experimenting. These students did not formulate research questions focused on the acquisition of conceptual knowledge. Germann, Odom, Aram and Burke (1996) applied their test for measuring science process skills with high school students in middle classes. Four of ten tasks in this test were related to the pre-experimental phase: Skills in formulating a research question, in determining manipulable variables for an experiment, in generating a hypothesis, and in planning activities to decide on a hypothesis to answer the research question. With these pre-experimental tasks, only about half of the students involved in this study attained levels which are sufficient for controlling their further experimental activities.

To realize pre-experimental phases as meaningful learning activities, another prerequisite is that learners activate their already acquired domain-specific knowledge for deriving research questions and formulating testable hypotheses as provisional answers to such questions. This is necessary for further elaborating and restructuring the already existing knowledge thus preventing a mere accumulation of isolated facts and the acquisition of non-integrated knowledge in pieces. Already in formulating their research questions in the pre-experimental phase, students should access their prior knowledge. Several studies conducted by Klahr (2000) provide arguments for this demand. In these studies, undergraduates had to find out causal knowledge by performing experiments. The results revealed that the most effective learners were those who first accessed their prior knowledge for formulating questions before they began to manipulate the materials in the experimental phase. Students who approached experimenting in this way are called 'theorists'. They required only half of the time to find out causal laws than the so called 'experimenters'. In contrast to 'theorists', 'experimenters' conducted investigations and manipulated the materials intensively before they formulated a causal research question or developed a hypothesis. Thus, their experimenting is not controlled by previously formulated research questions that had been derived from their prior knowledge. This seems to be a rather non-efficient approach and may explain the poor learning performances of 'experimenters'.

From the findings about limitations in the realization of labwork in science education, it may be concluded that experimenting should be more completely implemented. Above all, the pre-experimental phase should be more strongly considered. This phase includes several cognitive activities that may be represented as a sequence of five procedural steps according to the authors of the current study (Figure 1).

[Insert figure 1 about here]

It is assumed that an inquiring way of knowledge development in chemistry starts with an observable phenomenon (step 1). Students should access their relevant prior knowledge in order to describe the observation and transform it into a research issue (step 2). The result should be a question which focuses on the extension of the already available knowledge.

Questions of this kind, heading for new insights, and further elaboration of the previous knowledge are called "epistemic" questions (step 3). The pre-experimental processes are continued by anticipating provisional answers to the generated epistemic question, an activity which corresponds to formulating hypotheses (step 4). The subsequent planning (step 5) aims at testing the provisional answers (hypotheses) by gathering evidence for deciding on their correctness.

In this procedural conception of the pre-experimental phase, the quality of the epistemic questions generated by the students plays a crucial role for the knowledge-acquisition process. Graesser, McNamara and VanLehn (2005) stressed the importance of asking explanatory ('deep') questions in all kinds of inquiry learning. Typical examples are "why"-questions (e.g. why did "X" occur?), which focus on causal antecedents, and "what-if"-questions (e.g. what are consequences if "X" occurs?), which are directed towards causal consequences (Graesser, Person & Huber, 1992). In contrast to so-called 'shallow questions' these deep-reasoning questions represent high-quality epistemic questions which contribute to searching for and acquiring causal knowledge. Moreover they enable self-regulated and explanation-centered learning by the students (Graesser et al., 2005). Costa, Caldeira, Gallástegui and Otero (2000) assume that deep-reasoning questions of this kind contribute in creating links among otherwise non-related units of knowledge and thus improve memorization. Acquiring interrelated and elaborated knowledge structures is a focus of Neber's (2004) approach to fostering epistemic questioning as well. The approach is based on a knowledge-acquisition model (Neber, 1997). According to this model, the acquisition of knowledge begins by acquiring 'facts', which consist of descriptive knowledge about concepts (definitions) and rules (e. g. formulated as a question: What is the definition of water hardness?). Facts alone represent incomplete knowledge because they lack information about task-specific use in terms of givens and purposes. Therefore, facts should be further expanded by elaborative activities involving the students. In order to transform factual knowledge into more flexibly usable and transferable knowledge, elaborations may proceed in two directions. On one hand, facts should be expanded by ‘conditions’ that are given or created in order to apply the facts. A question like “Why does substance X oxidize?”, which focuses on information about causal antecedents (Graesser et al., 1992), is an example of an epistemic question that focuses on conditions. On the other hand, facts should be expanded by ‘functions’ in terms of consequences or purposes of their use. The question “Is it possible to remove an inkblot with substance X?” serves as an example of a function-related epistemic question, which, in terms of Graesser et al. (1992) aims at acquiring information about causal consequences. Thus, conditional, as well as functional, questions correspond to the deep-level questions demanded by Graesser et al. (2005). Student-active experimentation in science should contribute to the active transformation of factual knowledge which has been already acquired by the students (e. g. by more receptive instructional methods like lessons in the regular classroom). Pre-experimental labwork involving the generation of epistemic questions might contribute to access and further elaborate facts into conditionalized and functionalised knowledge.

But, if the spectrum of activities will be extended to the neglected pre-experimental phase, students will require help and support for performing these activities. Procedural deficits have been found with experimenting for all partial processes of this phase (see Figure 1). Concerning the access of prior knowledge, Anderson and Roth (1989) provided evidence that students use their factual knowledge in science only for reproducing it on demand but not for investigating and explaining new phenomena or for transforming it by solving problems. Concerning epistemic questioning, Graesser et al. (2005) realized that even undergraduates do not spontaneously formulate what they call deep-level causal questions. Concerning the anticipation of answers to formulated questions, findings by Zehren (2006) might be interesting. He instructed 200 high-school students to write research questions about given chemical phenomena before investigating the phenomena in the lab. More than 95% of the epistemic questions did not include any anticipated answer or an expectation in terms of an explicit hypothesis (e. g. only “Which kind of gas is in the gas lighter?”, but not “Is methane in the gas lighter?”). Finally, a pilot study on promoting pre-experimental epistemic questioning in high-school students provided evidence that structured support is necessary to raise the level of students’ research questions (Anton, Hergeth & Neber, 2006). In this case, allowing time for developing research questions, without prescribing the direction and level of such questions, resulted in few questions on conditions and functions, and in a very limited use of prior knowledge, as indicated by only a few chemical terms found in the formulated questions. In addition, the questions had been insufficiently related to possible observations or measurable variables, and were not useful in planning and controlling further experimental activities in the lab. Only providing additional time for planning investigations, without further structuring the activities of the students, had negative effects on students’ preferences for chemical experimentation under open conditions. Therefore, higher qualities of pre-experimental activities and more positive motivational effects might be attained by providing more explicit procedural help and support for the distinguished cognitive processes (Figure 1).

The general research question of the present study consists in investigating cognitive and motivational effects of explicitely supported pre-experimental activities of tenth-graders in planning chemical investigations. The effects measured were compared to those attained in a regularly instructed classroom whose students were not explicitely supported in their pre-experimental activities. From the intervention, we expected and hypothesized the following positive effects:

1. A higher motivation in chemistry in terms of more positive expectations concerning the capability to achieve (self-efficacy) and a higher value for learning chemistry (intrinsic value).
2. An increase of students' preference for experimenting under open and less prescribed conditions in chemistry, and a decrease in preference for experimenting under structured and strongly prescribed conditions.
3. More intense cognitive activities (thinking) of the students in dealing with the topics of the chemistry lessons. In particular, we expected higher intensities of knowledge- and question-related thoughts during the intervention and, as a transfer effect, during a lesson subsequent to the intervention.
4. Better quality of epistemic research questions formulated by the students. In particular, we expected more extensive use of acquired knowledge in chemistry during the formulating epistemic questions phase and we expected higher rates of questions aiming at the acquisition of conditional and functional chemical knowledge.

Method

Participants

The sample consisted of 53 students (27 male, 26 female) from two tenth-grade high school classrooms. Both classes attained a comparable performance level in chemistry (in terms of grades) and had been taught for about one school-year by the same female chemistry teacher. By chance, one of the classes was taken as the experimental group (n=28), and the other as the control group (n=25). All data were gathered anonymously by questionnaires.

Procedure, materials, and instruments

The study proceeded in three phases: Pretest, intervention, and posttest. Differences between variables repeatedly measured by self-report scales in the pre- and posttest phases were used to decide on the two hypotheses related to motivational effects of the intervention (hypothesis 1: self-efficacy in chemistry and value; hypothesis 2: preferences for open and for structured experimentation in chemistry). Measures taken in the intervention phase and additional variables only measured in the posttest phase were used to decide on the hypotheses related to cognitive effects (hypothesis 3: knowledge- and question-related thoughts; hypothesis 4: quality of epistemic questions).

Pretest phase

As motivational variables, chemistry-related self-efficacy and the perceived intrinsic value of chemistry were measured by subscales of the Motivated Learning Strategies Questionnaire (Pintrich & DeGroot, 1990). Each of the 18 items was answered on seven-point scales by the students of the experimental and the control group (1:not at all true of me; 7:very true of me). Related to experimenting in chemistry, two preferences for degrees of structure for labwork in chemistry were measured by a recently developed self-report instrument (Neber & Schommer-Aikins, 2002). The preference for open experimenting, i. e. for a more self-directed execution of the different phases of labwork is distinguished from the preference for structured experimenting, i. e. favouring more prescribed and prestructured activities. Each of the two preference-variables was measured by five items which were answered on five-point scales (1:not true; 2:very true). Table 1 provides a summary of the variables which have been measured in the pre- and posttest.

Intervention phase

First instructional unit

The intervention phase covered two instructional units. In the first part of the first unit, both experimental and control groups were treated in the same way. In the beginning, both classes discussed the theme ‘experimenting in chemistry’ for about ten minutes. The teacher acted as a mentor providing general issues (e. g. What is the role of questions in experimenting?), and moderated the discussion in a non-directive way. Subsequently, for a very short period (about six minutes), each student cooperated with a partner in order to formulate their positions on the issues discussed beforehand and they communicated their positions in a short discussion in the class. Afterwards, the experimental and the control groups were treated differently. For the rest of the first instructional unit, the students of both classes continued to work individually (for about 20 minutes). In the experimental group the quality of research questions was strengthened, whereas the control group focused on the quantity of questions.

Experimental group: Each student received short descriptions of two chemistry observations (1: an iron rod rusts; 2: a flower changes colour). For each observation, students were instructed to write down one research question. Subsequently, further high-quality questions could be formulated about the observations. The students of the experimental group were provided with the following three criteria for the quality of research questions: Degree of answerability, degree of relevance to chemistry, and degree of cause-effect relatedness. The students rated each of their questions on these three dimensions. All ratings were performed on five-point scales (1:not at all; 5:very true).

Control group: These students also received the same two short descriptions of observations. They were instructed to write as many questions about these observations as possible. Neither the quality of the questions was mentioned nor the criteria for rating the quality of the questions were provided. Thus, for these students, the quantity of questions was strengthened.

Second instructional unit

Experimental group: An informed training in formulating epistemic questions for an experiment in chemistry was conducted. First, the class received example-based information about the importance of epistemic questions for the acquisition of knowledge. Differences between questions for facts versus for conditions and functions (causality) were illustrated by examples of such questions. The training proceeded in four phases which covered all cognitive activities in the pre-experimental phase (as depicted in figure 1).

In the first phase, students' prior knowledge of chemistry was activated. At the beginning, students received a short description of a chemistry observation ('If water is repeatedly boiled in a saucepan, a white coating will develop'). Then, corresponding knowledge of chemistry which had been taught in the previous lessons was activated by providing ten items. The items consisted of a mixture of statements (‘a halogen is…’), multiple-choice items, and free-answer questions.

In the second phase, the students formulated a ‘good’ question for an experiment on the observation. They were instructed that a “good” question should be based on prior knowledge relevant to the chemistry observation and that the question should aim at getting information about chemical causes or effects. To facilitate the generation of a question of this kind, four written non-elaborated question stems were provided to the students (King, 1995). According to Rosenshine, Meister and Chapman (1996), question stems represent one of the most effective approaches to promoting the quality of student questions even with very short-term interventions. The question stems used in this study should help students formulate causal-explanatory questions for conditions or functions instead of simply asking questions about facts (e. g. ‘What does water hardness mean?’). Therefore, each of two sets of stems prestructured a question for conditions (e. g. ‘Is/will it … because of …?’) and for functions (e. g. ‘Does … result in …?’). Students were obliged to use one of the four stems for framing their written “good” question.

In the last two phases of the second instructional unit, the students worked in dyads. This set-up was chosen to further strengthen the involvement of the students, to prevent succer/loafing effects which may occur in larger groups (only one student in the group is doing the work), and to limit the complexity of the task (discuss the quality of not more than two questions in the group). Therefore in the third phase, the dyad groups decided on which of their previously formulated two “good” questions (one from each dyad member) should finally be selected for planning an investigation. They were explicitly requested to observe the already introduced criteria for ‘good’ research questions (answerability, chemical relevance, cause-effect) in evaluating their questions. After deciding on one of the two questions, the students (dyads) formulated an anticipated answer to the chosen question.

In the fourth phase, the dyads planned the experiment to check their anticipated answer to the question. They were instructed to note down all sequential steps which are necessary to unambiguously verify or falsify their answer.

Control group: These students attended regular classroom instruction. The lesson was organized around the same chemically relevant observation (white coating) and on acquiring chemical knowledge on water hardness for explaining the observation. Yet, in contrast to the experimental group, instruction was delivered in a teacher-centred way. Research questions, repetition of relevant curricular contents already instructed, anticipated outcomes, arguments, and planning was all done and demonstrated by the teacher. Meta-information about functions and epistemic qualities of questions was not provided or discussed. Altogether, the control class spent the same amount of time related to pre-experimental activities as the experimental group.

Posttest phase

As already described, in the posttest, after the two units of the intervention phase, the pretest variables (motivation, preferences) were measured again. In addition, all participants retrospectively rated the intensities of their knowledge- and question-related thoughts during the second unit of the intervention, and again, related it to a regular chemistry lesson after the intervention. For knowledge-related thoughts, three items were used (extent of thinking about prior knowledge, causes/conditions of observations, and consequences/functions). Another three items applied to question-related thoughts (extent of thinking about reasons for possible questions, wording of the questions, and quality of the questions). All items were answered on five-point scales (1:not at all true; 5:very much true). Finally, the skill in formulating research questions was measured in the posttest phase. To this end, short written descriptions of two observations were provided to the students. The first consisted in a repetition of one of the observations already provided in the intervention phase (observation 2: flower changes colour). The other observation (observation 3) was only provided in the posttest ('Calcium sulphate is mixed with water. One hour later, the mass is hard as stone'). Students were instructed to note down one 'good' research question for each observation. The questions generated were analysed for their epistemic direction (questioning for facts, conditions, or functions) and for the number of chemical terms used in formulating the question. Each question was also rated for its quality by two experts (on five-point scales; 1:very low; 5: very high). The experts considered the content and the adequacy of the questions for planning an experiment.

Results

The questionnaires for motivation in chemistry and preferences for experimentation in the pre- and posttest proved to be reliable instruments for measuring these variables (α-scores for reliabilities range between .66 and .94). Table 1 shows the reliabilities achieved in the current study and provides examples of items of the four questionnaires. Reliabilities for the instrument used for rating the intensities of students' thoughts in the posttest are not reported in this table because these intensities have only been measured by single self-report items.

[Insert table 1 about here]

In the following, the results of the study will be reported in the order of the four hypotheses formulated above.

For deciding on the first two hypotheses (motivation in chemistry, preferences for experimentation), changes of the corresponding four variables (means) from pre- to posttest were considered. Differences in the changes of the means between experimental group (‘E’) and control group (‘C’) were compared and tested by applying a repeated measures MANOVA. Table 2 depicts the means (M) and standard deviations (SD) of the pre- and the posttest measurements of all four variables, separated for the experimental (E) and the control (C) group.

[Insert table 2 about here]

Pre-posttest-changes of the motivational variables did not significantly differ between the experimental and the control group (both p-values for the F-test scores >.05). Thus, the intervention had no specific effect on students’ motivation in chemistry (self-efficacy, intrinsic value). Contrary to the first hypothesis, the intervention in the experimental group did not result in the expected positive effects on these motivational variables. Therefore, the first hypothesis is not confirmed by the data.

With the second hypothesis, an increase of the preference for open experimentation and a decrease in preference for structured experimentation was assumed.. Together with the results of the statistical tests, the pre-post-changes in the means of both variables are depicted in table 2. For the changes in the preference for open experimenting, a significant level was attained (p=.04). Here, the intervention in the experimental group resulted in an increase of this preference. In contrast, pre-posttest changes of the preference for structured experimentation were the same in both groups. Thus, the data confirms the first part of the second hypothesis, as the intervention contributed in increasing students' preference for open experimentation. The second part of this hypothesis was not confirmed by the data, as the intervention did not result in a lower preference for structured experimentation.

For getting more differentiated insights about the effects on the preference for open experimenting, the changes of each of the five single items measuring this variable were analyzed by comparing pre- and posttest means of each of these items (figure 2). These differences between the means were tested by t-statistics. For the experimental group, the t-tests for dependent samples resulted in significant differences for the preference in the self-planning of an experiment (p=0.02), and for the preference for own decisions on how to represent the results of an experiment (p=0.04). For the experimental group, the posttest mean for the preference in deriving own research questions was considerably higher than for the control group, but without attaining significance (p=0.057). Anyway, these analyses on the item level indicate that the intervention in the experimental group had clear positive effects on almost all measured aspects of the preference for experimenting under more open conditions, and, in this respect, confirming the second hypothesis.

[Insert figure 2 about here]

Knowledge- and question-related cognitive processes. Retrospective ratings of students' thought processes were taken to decide on the third hypothesis (assuming more intensive thoughts about knowledge and about possible research questions by students in the experimental group). The first retrospective rating (rating 1) aimed at intensities of students' knowledge- and question-related cognitive processes (thoughts) during the second unit of the intervention phase. The second retrospective rating (rating 2) was carried out immediately after both groups attended a regular teacher-led chemistry class after the intervention phase. In both ratings, the intensities of three aspects of knowledge- and of question related thoughts were covered. Knowledge-related processes had been thoughts about the students' own prior knowledge about the given and described observation, about chemical causes (conditions) related to the given observation, and about consequences or purposes (functions) related to the phenomenon. Question-related thoughts, which involve reasoning about possible research questions,reflecting on the wording of such questions, and generally thinking about the quality of possible research questions, might be stimulated during the intervention and the lecture. Means (M) and standard-deviations (SD) of the six retrospectively measured variables for both ratings (intervention-phase, posttest-phase) are depicted in table 3. The results of the experimental- and the control-group have been compared and tested by a MANOVA for all variables. The outcomes (F-values) and the probabilities (p) are presented (table 3).

[Insert table 3 about here]

According to the results of the first rating (see table 3), during the intervention, the participants of the experimental group reflected much more intensively on their prior knowledge, about causes to explain the observation, and on all aspects concerning research questions. Thus, for the intervention phase, the data confirm the third hypothesis.

With the second rating (rating 2: lecture after the intervention), the possible non-trivial transfer of these cognitive processes to regular instruction with no hands-on or explicitly fostered pre-experimental activities was tested. Here, only few differences could be found in favour of the experimental group (see table 3). Seemingly, the students of the experimental group continued in thinking more intensively about chemical causes for the observations and phenomena treated in the class, and they reflected more intensively about reasons for the research questions presented in the class. From the results of both ratings, it may be inferred that the promotion of pre-experimental activities had positive effects on the transfer of the supported cognitive processes (thoughts) beyond the training situation itself, thus confirming the third hypothesis.

Skills in formulating epistemic research questions. With the fourth hypothesis, it is expected that, after the intervention, students in the experimental group would formulate relatively more epistemic questions for conditons and functions, and use their prior knowledge to formulating the questions. This hypothesis was tested by generating two possible research questions on given observations in the posttest phase. (observation 2: flower changes its colour; observation 3: calcium sulphate gets hard). The questions of the participants have been analyzed according to three aspects: Epistemic direction (three categories: for facts, for conditions, or for functions), number of chemical terms in the question (as an indicator of using prior chemical knowledge), and the quality of the question as rated by experts (chemists). In table 4, examples of questions written by the participants on the calcium sulphate observation are presented together with their classifications. The question “why does calcium sulphate gets hard?” represents an example of a question for conditions (take a known consequence and ask for its assumed cause). The question “does the addition of water keep calcium sulphate in liquid form?” exemplifies a question for functions (take a possible causal factor and ask for its assumed consequence). The question “how hard is stone?” illustrates a question for facts and, at the same time, a question of the lowest quality level (not testable and no depth).

[Insert table 4 about here]

Before the intervention started, both groups produced questions that were similarly distributed on the three epistemic directions (facts, conditions, and functions).Whereas in the posttest after the intervention, the questions generated for the two observations (2: flower changing the colour; 3: calcium sulphate) were differently distributed on the three categories in the two groups (figure 3). These distributions were tested by applying non-parametric tests which provided measures in terms of U-statistics. In particular, the students of the experimental group formulated a significantly higher proportion of questions for causes (conditions), and fewer questions for facts about the calcium sulphate observation (question 3; U=250; p=0.04). Seemingly, and as intended, the intervention promoted the tendency to ask more deep-level questions for causes. In this respect, this result confirms the fourth hypothesis.

[Insert figure 3 about here]

The number of chemical terms in the questions formulated by both groups served as indicators of students’ using acquired knowledge. The results for “chemical terminology” are depicted in table 5 for the two questions formulated in the pretest phase and in the posttest phase. Again, differences could only be found for posttest questions. Students in the experimental group used more chemical terms in formulating their posttest questions about the flower observation (observation 2 posttest; table 5). This indicates that the promotion of the pre-experimental activities increased the tendency to consider prior knowledge in framing research questions. This result may be taken as a confirmation of the fourth hypothesis.

[Insert table 5 about here]

Finally, the same applies to the expert ratings of the quality of the questions. Here again, the difference was very significant in favour of the experimental group only for the question about observation 2 in the posttest (flower changes colour) (see table 5). No differences appeared for questions about observation 3 (calcium sulphate) in the posttest. Nevertheless, the results on epistemic directions of students' questions, on the use of chemical terminology, and on experts' ratings of the quality of the questions may be taken as a confirmation of the fourth hypothesis. Accordingly, skills in formulating higher-quality epistemic questions for chemistry experiments have been supported by the intervention applied in the experimental group.

Discussion

In terms of activating prior knowledge, asking epistemic questions, assuming hypothetical answers, and planning a research question, a cycle of pre-experimental cognitive processes has been established and promoted that should precede hands-on activities (Tobin, 1998). In this study, different methods were applied to foster these processes. Compared to a prior pilot study by the authors (Anton et al., 2006), the most important methodological change consisted in a more structured method in stimulating students' research questions in the experimental group. The epistemic direction of the questions was derived from a model of knowledge and the students were instructed to generate research questions that aimed at knowledge beyond the level of mere descriptive facts. This was attained by using a question-stems approach, which has proved to be successful in improving the quality of students' question-asking in different domains (King, 1995; Neber, 2004). In a review of question-training studies, Rosenshine et al. (1996) concluded that even with short interventions that use question stems, positive effects on raising the cognitive level of students' question-asking can be expected. The results of this study seem to confirm this conclusion. Even though the investigation was conducted with a rather small sample of students, several of the hypotheses could be confirmed by the data.

In particular, after the intervention, the students in the experimental group generated a significantly higher proportion of research questions that asked for causes (conditions) than the students in the control classroom. Whereas, before the intervention, the epistemic directions of students' research questions did not differ between the two groups. An open issue remains why this difference, in favour of the experimental group, only applied to formulating epistemic questions for conditions and, further, why both groups formulated so few questions for chemical functions (consequences). A possible explanation might be that this was due to the kind of observations or tasks presented in this study. To decide on this explanation, further investigations comparing the effects of a larger variety of given observations and tasks relating to students' generation of research questions is required. Johnstone's (1993) categorization of problem-structures in science and classifications of chemical tasks in terms of their memory load (Tsaparlis & Angelopoulos, 2000) might be useful for systematically deriving a spectrum of observations and tasks that could be presented to the students in the pre-experimental phase.

Besides having effects on the direction and content of the questions, the intervention resulted in a clear tendency for students' in the experimental group to strongly consider their prior knowledge when formulating research questions. This result may be taken as evidence that a structured support of pre-experimental processes is necessary for accessing prior knowledge and transforming it into more elaborated conditionalized knowledge by further labwork activities (Anton et al., 2006; Neber, 2004).

In addition, the intervention resulted in more intense thoughts about what to learn (knowledge related thoughts) and about possible investigations (thoughts about reasons for questions) in a regular chemistry lesson by students in the experimental group. Altogether, the three findings mentioned so far (epistemic direction of research questions, prior knowledge use, and more intense thoughts about epistemic goals during and after the intervention) may be taken as evidence that the structured help provided for the sequence of cognitive processes in the pre-experimental phase contributed to raising the quality of a student's search for knowledge. Thus, the approach applied in this study was shown to strengthen important cognitive skills that are required for students' self-direction of "complete" inquiry cycles. The further effect on the willingness of the students in the experimental group to get involved in more open forms of labwork (preference for open experimenting in chemistry) indicates that motivational prerequisites for procedurally-extended and open inquiry cycles have been positively influenced by the intervention.

Unlike the prior pilot study (Anton et al., 2006), the readiness to search for opportunities for research questions and to control inquiry processes on their own was not reduced but, rather, it increased. Seemingly the intervention prevented students from perceiving the extended scope for their own decisions (e. g. what to consider for an investigation, and what to hypothesize) as too difficult, and precarious for their self-system, as found by McRobbie et al. (2001). Again, this may be due to the clear sequential prescription of the pre-experimental activities and the structured support for formulating epistemic questions that was provided by obligatory question stems.

The hypothesized more general impact on motivation to learn chemistry could not be attained, even though such effects represent an important objective of chemistry education (Tuan, Chin, Tsai & Cheng, 2005) and may be achieved by investigative and inquiry-based learning environments (McIver et al., 2002). Neither self-efficacy in chemistry nor a higher intrinsic value of learning chemistry was promoted by the intervention. Attaining such broader effects may require more frequent opportunities for student questioning, a stronger integration of pre-experimental activities with other phases of inquiry cycles and, as a consequence, a broader transformation of chemistry classrooms towards more investigative environments (McRobbie et al., 2001).

Altogether, the approach realized in the current study may be relevant for chemistry instruction. Promoting pre-experimental processes may not only be necessary for preventing non-learning and unproductively in the lab (Johnstone & Al-Shuali, 2001). Beyond that, procedural skills that have been promoted in this study, like relating new observations and phenomena to the previous knowledge, and asking questions for getting additional information, represent component skills of a broader, multidimensional chemical literacy as assessed by Shwartz, Ben-Zvi and Hofstein (2006). These authors found that even in advanced high school chemistry courses such skills are not considered as teaching goals and the courses contribute little to acquiring them. Another reason for the difficulty to acquire such skills may be due to their complexity. In the present study, even the pre-experimental activities, representing only one of the phases of complete inquiry cycles, had to be decomposed into several subprocesses or procedural skills (see figure 1).

Fully mastering and automatizing the whole sequence of the subprocesses promoted in the experimental group may require more time and more repeated exercises than only a short-term intervention. This may be considered as a limitation of the study and may have prevented the attainment of more distinct transfer effects (e. g. knowledge- and question-related thoughts in succeeding lessons). Another limitation consists in the isolated treatment of pre-experimental activities. Therefore, it was not possible to measure effects on other phases of inquiry cycles (on succeeding experimental processes and post-experimental activities). Finally, it should be mentioned that some of the methods applied to promote pre-experimental subprocesses in the intervention may have been sub-optimal. Using dyads as the organizational structure for formulating epistemic research questions in the experimental group could serve as an example. Other forms of cooperative learning may be more effective for this purpose. Nevertheless, at least some of the methods applied in the study may be useful for a structured support of otherwise neglected activities.

Acknowledgements

The authors thank the reviewers for their comments on previous drafts. Their suggestions contributed much in improving our paper.

References

Anderson, C.W., & Roth, K.J. (1989). Teaching for meaningful self-regulated learning of science. In J. Brophy (Ed.), *Advances in research on teaching. Vol. 1* (pp. 265-305). Greenwich, CT: JAI Press.

Anton, M. A., Hergeth, T., & Neber, H. (2006). *Experimenting in chemistry: the role of question asking*. University of Munich: Department of Chemistry.

Carey, S., Evans, R., Honda, M., Jay, E., & Unger, C. (1989). 'An experiment is when you try it and see if it works': a study of grade 7 students' understanding of the construction of scientific knowledge. *International Journal of Science Education, 11*, 514-519.

Costa, J., Caldeira, H., Gallástegui, J. R., & Otero, J. (2000). Analysis of question asking on scientific texts explaining natural phenomena. *Journal of Research in Science Teaching*, *37*, 602-614.

Domin, D. S. (1999). A review of laboratory instruction styles. *Journal of Chemical Education, 76*, 543-547.

Doran, R. L., Lawrenz, F., & Helgeson, S. (1994). Research on assessment in science. In D. Gabel (Ed.), *Handbook of research in science teaching and learning* (pp. 388-442). New York: Macmillan.

Germann, P. J., Odom, A. L., Aram, R., & Burke, G. (1996). Student performance on asking questions, identifying variables, and formulating hypotheses. *School Science and Mathematics*, *96*, 192-200.

Graesser, A. C., Person, N., & Huber, J. (1992). Mechanisms that generate questions. In T. W. Lauer, E. Peacock, & A. C. Graesser (Eds.), *Questions and information systems* (pp. 167-187). Hillsdale, NJ: Erlbaum.

Graesser, A. C., McNamara, D. S., & VanLehn, K. (2005). Scaffolding deep comprehension strategies through Point & Query, AutoTutor, and iSTART. *Educational Psychologist*, *40*, 225-234.

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

Johnstone, A. H. (1993). Introduction. In C. Wood & R. Sleet (Eds.), *Creative problem solving in chemistry* (pp. IV-VI). London: The Royal Society of Chemistry.

Johnstone, A. H., & Al-Shuaili, A. (2001). Learning in the laboratory: some thoughts from the literature. *University Chemical Education, 5*, 42-51.

King, A. (1995). Cognitive strategies for learning from direct teaching. In E. Wood, V. E. Woloshyn, & T. Willoughby (Eds.), *Cognitive strategy instruction* (pp. 18-65). Cambridge, MA: Brookline Books.

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

Lazarowitz, R., Tamir,P. (1994). Research in using laboratory instruction in science. In D. L. Gabel (Ed.), *Handbook of research in science teaching and learning* (pp. 94-128). New York: Macmillan.

Lederman, N. G. (2004). Scientific inquiry, and science education reform in the US. *Science Education, 88*, 402-404.

Lunetta, V. N. (1998). The school science laboratory: Historical perspectives and context for contemporary teaching. In B. J. Fraser, & K. G. Tobin (Eds.), *International handbook of science education. Volume 1* (pp. 249-262). New York: Macmillan.

MacIver, D. J., Young, E. M., & Washburn, B. (2002). Instructional practices and motivation during middle school (with special attendance to science). In A. Wigfield, & J. S. Eccles (Eds.), *Development of achievement motivation* (pp. 333-351). San Diego: Academic Press.

McRobbie, C. J., & Thomas, G. P. (2001). Changing the learning environment to enhance explaining and understanding in a year 12 chemistry classroom. *Learning Environments Research*, *3*, 209-227.

Neber, H. (1997). Promoting the generation of usable knowledge. In J. H. M. Hamers & M. T. Overtoom (Eds.), *Teaching thinking in Europe. Inventory of European programmes* (pp. 255-260). Utrecht: Sardes.

Neber, H. (2004). Promoting epistemic questioning of students. In H. Pedrosa de Jesus, & H. van der Meij (Eds.), *First international seminar on research on questioning*. CD-ROM. Aveiro, Portugal: University of Aveiro.

Neber, H., & Heumann-Ruprecht, D. (2006). Discovery learning by experimenting in chemistry. In I. Hertzstell (Ed.), *From the Nurenberg funnel to the laptop* (pp. 289-298). Bonn, Germany: DPV.

Neber, H., & Schommer-Aikins, M. (2002). Self-regulated science learning with highly gifted students: the role of cognitive, motivational, epistemological, and environmental variables. *High Ability Studies, 13*, 59-74.

Pedrosa de Jesus, H., Teixeira-Dias, J. J. C., & Watts, H. (2003). Questions of chemistry. *International Journal of Science Education*, *25*, 1015-1034.

Pintrich, P. R., & DeGroot, E. V. (1990). Motivational and self-regulated learning components of classroom academic performance. *Journal of Educational Psychology, 82*, 33-40.

Rosenshine, B., Meister, C., & Chapman, S. (1996). Teaching students to generate questions: A review of the intervention studies. *Review of Educational Research*, *66*, 181-221.

Schauble, L., Glaser, R., Raghavan, K., & Reiner, M. (1991). Causal models and experimentation strategies in scientific reasoning. *The Journal of the Learning Sciences*, 1, 201-238.

Séré, M.-G. (2002). Towards renewed research questions from the outcomes of the European project Labwork in Science Education. *Science Education*, *86*, 624-644.

Shwartz, Y., Ben-Zvi, R., & Hofstein, A. (2006). The use of scientific literacy taxonomy for assessing the development of chemical literacy among high-school students. *Chemistry Education Research and Practice, 7*, 203-225.

Tobin, K. G. (1990). Research on science laboratory activities: In pursuit of better questions and answers to improve learning. *School Science and Mathematics, 90*, 403-417.

Tobin, K. G., & Capie, W. (1982). Relationships between formal reasoning ability, locus of control, academic engagement, and integrated process skill development. *Journal of Research in Science Teaching, 19*, 113-121.

Tuan, H.-L., Chin, C.-C., Tsai, C.-C., & Cheng, S.-F. (2005). Investigating the effectiveness of inquiry instruction on the motivation of different learning styles students. *International Journal of Science and Mathematics Education*, *3*, 541-566.

Tobin, K. (1998). Issues and trends in the teaching of science. In B. J. Fraser, & K. G. Tobin (Eds.), *International handbook of science education* (pp. 129-151). Dordrecht, NL: Kluwer.

Tsaparlis, G., & Angelopoulos, V. (2000). A model of problem solving: Its operation, validity, and usefulness in the case of organic-synthesis problems. *Science Education, 84*, 131-153.

Zehren, W. (2006). *Learning in the extra-curricular chemistry laboratory*. Saarbruecken, Germany: Department of Chemistry at the University of Saarbruecken.

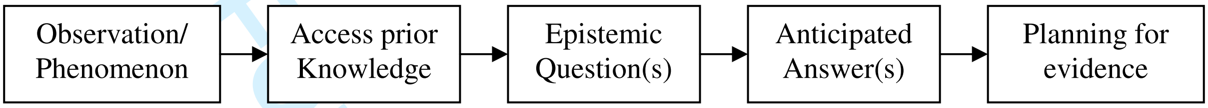

Figure 1. Sequence of cognitive activities in the pre-experimental phase according to Neber and Anton

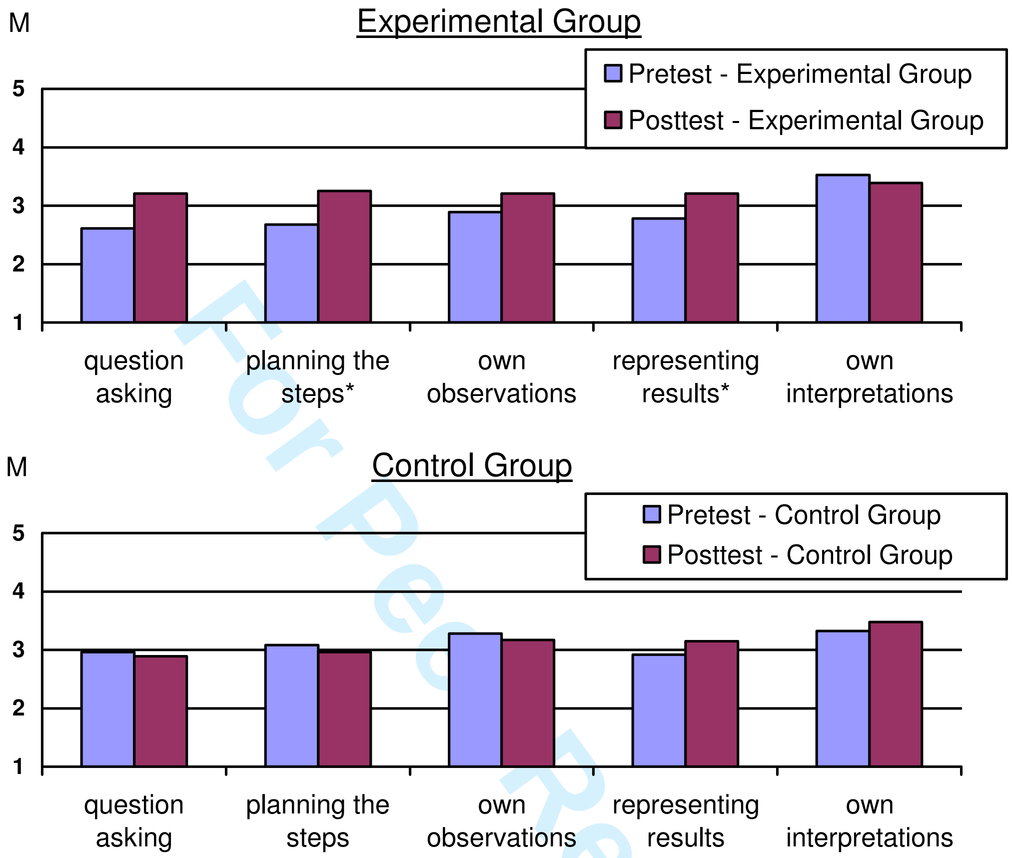

Figure 2. Pre- and posttest means of five items measuring the preference for open experimentation in the experimental and the control group

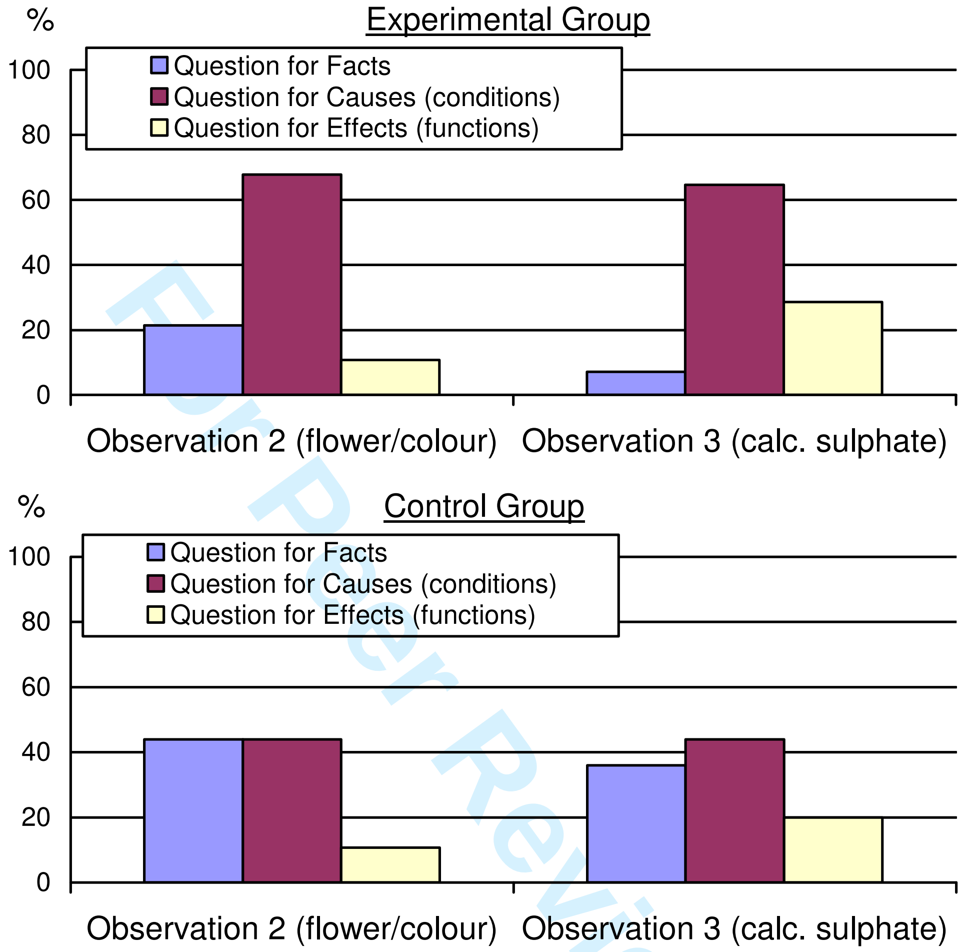

Figure 3. Epistemic directions of research questions in the experimental- and the control group formulated for two given observations in the posttest phase

Table 1. Instruments, variables, and reliabilities in pre- and posttest

Referential Context	Variables (number of items)	Examples (answering scale)	Authors	Reliability (α) Pre	Post
Chemistry	Self efficacy (9)	I know that I will be able to learn the material for the chemistry class (1-7)	Pintrich & DeGroot, 1990	0.93	0.94
	Intrinsic value (9)	It is important for me to learn what is being taught in this class (1-7)		0.81	0.90
Experimenting in Chemistry	*Preferences for …*	I prefer experiments …	Neber & Schommer-Aikins, 2002		
	Open experimenting (5)	.. for whom I can develop my own research question (1-5)		0.66	0.83
	Structured experimenting (5)	.. whose steps are clearly prescribed (1-5)		0.76	0.75

Table 2. Changes in achievement motivation, and preferences for the degree of structure of experimenting in chemistry classes[1]

Referential Context	Variables	Group[2]	Pretest M	SD	Posttest M	SD	$F_{(1,51)}$	p
Chemistry	Self efficacy	E	4.06	1.04	3.87	1.11	0.27	0.61
		C	3.92	1.35	3.82	1.31		
	Intrinsic value	E	4.55	0.78	4.36	1.05	0.29	0.59
		C	4.26	1.04	4.16	1.18		
Experimenting in chemistry	Preferences for …							
	Open experimenting	E	2.90	0.49	3.26	0.81	3.91	0.04
		C	3.11	0.72	2.99	0.86		
	for Structured experimenting	E	3.31	0.65	3.25	0.72	0.17	0.68
		C	3.14	0.85	3.30	0.86		

[1] :multivariate F for the interaction of repeated measurement * group: $F_{(5,47)}$=1,49; p=0.21

[2] : E: Experimental group C: Control group

Table 3. Retrospective intensity-ratings of knowledge- and question-related thoughts by students of the experimental- and the control group[1]

	Variables	Rating[1]	Experimental group[3]		Control group[3]			
			M	SD	M	SD	$F_{(1,51)}$	p
Knowledge-related thoughts	about prior knowledge	1	3.82	1.05	2.96	1.24	7.45	0.01
		2	3.07	0.98	2.72	1.03	1.63	0.21
	about causes (conditions) [2]	1	3.75	1.04	2.56	1.00	17.8	0.00
		2	3.28	1.05	2.68	0.99	4.64	0.04
	about consequences (functions) [2]	1	2.96	1.07	2.72	1.10	0.67	0.41
		2	3.14	0.93	2.96	1.09	0.43	0.51
Question-related thoughts	about reasons for questions	1	3.67	0.90	2.40	1.08	21.9	0.00
		2	3.25	0.97	2.52	1.04	6.97	0.01
	about the wording of questions	1	3.75	1.05	2.88	1.31	5.36	0.03
		2	2.39	0.95	2.64	1.04	0.81	0.37
	about the quality of questions	1	3.35	1.02	2.56	1.12	7.30	0.01
		2	3.03	0.92	2.76	1.13	0.96	0.33

[1]:rating 1 relates to thoughts during the second instructional unit of the intervention phase; rating 2 relates to thoughts in a regular chemistry class after the intervention
[2]: rating 1: 11 of 14 dyads of the experimental group planned an experiment on a question for conditions/causes of the observation; only 3 dyads on a question for functions
[3]: multivariate $F_{(7,45)}$=5,41; p=.00

Table 4. Classification of students' epistemic research questions

Questions about observation 3: calcium sulphate	Epistemic direction[1]	Terminology[2]	Quality[3]
What is the chemical formula for calcium sulphate?	fact	1	1
How hard is stone?	fact	0	1
Why calcium sulphate gets hard?	condition	0	1
Which temperature is necessary to keep the mass in liquid form?	condition	2	3
Does the addition of water keeps calcium sulphate in liquid form?	function (consequence)	0	2
Which substances are left over after the water disappeared?	function (consequence)	1	3
Why is calcium sulphate more strongly combined with water after they have been mixed?	condition	1	3
Does the reaction of calcium sulphate and water produce heat that vaporizes the water?	condition	3	4

[1]:facts, conditions, or functions
[2]:number of chemical terms in the question
[3]:expert rating: 1: lowest quality; 5: highest quality

Table 5. Chemical relevance of students' questions in pre- and posttest

variables	Experimental Group		Control Group		$F_{(1,51)}$	U[1]	p
	M	SD	M	SD			
PRETEST							
Question about observation 1:							
chem. terminology	1.07		1.08			326	0.36
chemical quality	1.96	0.58	1.64	0.63	3.72		0.06
Question about observation 2:							
chem. terminology	1.09		1.07			347	0.91
chemical quality	1.96	0.63	1.72	0.45	2.51		0.12
POSTTEST							
Question about observation 2:							
chem. terminology	1.39		1.12			254	0.02
chemical quality	2.14	0.45	1.84	0.38	7.03		0.01
Question about observation 3:							
chem. terminology	1.42		1.24			284	0.15
chemical quality	2.15	0.65	2.00	0.76	0.54		0.46

[1]: numbers of chemical terms in the questions (chemical terminology variables) were not normally distributed and thus non-parametrically tested (U-values from Mann-Whitney tests)