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Open Experimentation on Phenomena of Chemical Reactions via the Learning Company Approach in Early Secondary Chemistry Education

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Presented is a case study on the implementation of open and inquiry-type experimentation in early German secondary chemistry education. The teaching strategy discussed follows the learning company approach. Originally adopted from vocational education, the learning company method is used to redirect lab-oriented classroom practice towards a more cooperative mode of learning and instruction. In our interpretation of this method for chemistry education, an additional methodological element was implemented in order to create an atmosphere allowing a different style of experimentation. Our interpretation of the learning company idea seeks to motivate students to perform self-regulated and self-organized experiments within the sought after cooperative mode. This paper describes an example using the phenomena of chemical reactions as developed within a project of Participatory Action Research. It also provides insight into both teacher and student feedback, concluding by relating our findings to other examples using the learning company approach in chemistry education.

Keywords: Chemistry Education, Cooperative learning, Open Experimentation, Learning Company, Participatory Action Research

INTRODUCTION

There seems to be unanimous agreement that labwork is an essential component of modern secondary school chemistry teaching (Nakhleh, Polles, & Malina, 2002). Over the years, labwork has repeatedly been characterized as having great potential for students to acquire chemistry content knowledge. It also is seen as essential, allowing students to understand of the scientific method (Blosser, 1983) and the nature of science (Duschl, 1990).

Nevertheless, time hasn't necessarily confirmed such claims. Repeated, extremely cautious remarks have emerged that labwork's positive role for chemistry learning is not self-evident, either in cognitive achievement or in learning about the scientific method. Nor has it been shown that labwork automatically leads to a modern understanding of the nature of science (e.g., Hofstein & Lunetta, 1982; Tobin, 1990; Hofstein, 2004). Such cautious remarks have increasingly been supported by empirical research evidence (Lunetta, 1998; Nakhleh et al., 2002; Hofstein, 2004).

Lunetta (1998, p. 250) gave us a clear idea for why the success of most school laboratory practices is so insufficient, basing his arguments on Champagne, Gunstone, and Klopfer (1985), Eylon and Linn (1988),

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State of the literature

- Laboratory work often does not fulfill its intentions in promoting effective science learning and learning about the nature of science.
- Research asks for more open and inquiry-based tasks for learning in the lab.
- Cooperative learning has proofed to be a successful strategy for enhancing the quality of lab instruction.

Contribution of this paper to the literature

- The learning company approach is presented as a new and innovative mode for cooperative learning in the science classroom.
- The potential of the learning company approach is described to offer a motivating framework for open experimentation and cooperative learning in the lab.
- Experiences about the application of the learning company approach in the lower secondary chemistry classroom are reported along a new example dealing with phenomena of chemical reactions.

and Tasker (1981). In one on his seminal reviews on the state-of-the-art in school laboratory classes he states:

"*Students often fail to understand the relationship between the purpose of the investigation and the design of the experiment which they had conducted, they do not connect the experiment with what they have done earlier, and they seldom note the discrepancies between their own concepts, the concepts of their peers, and those of the science community. […] To many students, a 'lab' means manipulating equipment but not manipulating ideas.*"

Lunetta demands more student thinking within laboratory tasks, meaning i.e. challenging and demanding pupils' cognitive activities beyond simple hands-on doing. For over 30 years now, similar comments along the same lines as Lunetta's ideas have been aired about the laboratory practices we have and those we should instead be actively developing (e.g. Bates, 1978; Tobin, 1990; Gunstone & Champagne, 1990; Herrington & Nakleh, 2003; or Hofstein, 2004). From the large amount of scholarly papers available, several suggestions for changes in the common practices of school chemistry experimentation have emerged. Perhaps the most often suggested change is that school labwork should go beyond "cookbook recipe" experiments (Tamir & Lunetta, 1981; Tobin, 1990; Kipnis & Hofstein, 2007). This means that experimental tasks need to be organized in a fashion where they become more cognitively challenging than a simple, prescribed hands-on activity can ever be. Such manual tasks can generally be categorized as mere word-for-word repetition, without a need for any further thinking on the part of the learner. This has lead to repeated pleas from researchers to open up experimental tasks and move towards inquiry-oriented modes of learning, which demand increased student self-regulation. This also necessitates the inclusion of the processes of planning, evaluation and experimental documentation as student-managed activities (Hofstein & Lunetta, 1982; Gunstone & Champagne, 1990; Witteck, Most, Kienast, & Eilks, 2007; Kipnis & Hofstein, 2007).

Another request for change was made by Nakleh et al. (2002), who reflected upon lab activities as the forefront to a distributed cognition framework. They suggested the use of more cooperative learning in the laboratory environment with an aim at recognizing the dynamic and interactive aspects of knowledge generation. Lunetta (1998) also argued for the consideration of the communicative aspect during lab activities, which should be more thoroughly based on essential components of cooperative learning such as those described in detail by Johnson and Johnson (1999). Just such a combination of lab-work and cooperative learning have already led to reports of positive development in achievements, including growing personal skills and self-esteem (Lunetta, 1990; Quin, Johnson & Johnson, 1995). Furthermore, Nakleh et al. (2002) also suggested thinking more thoroughly about different forms of assessment, using a focus on good group performance, e.g. the presentation of final results with posters.

Building upon this theoretical and empirical evidence, we developed the idea of the "learning company" approach in chemistry education. Two examples were developed for the topics acid-base-chemistry and the methods for separating matter (Witteck & Eilks, 2006a; Witteck, Most, Kienast, & Eilks, 2007). This paper describes a third example implemented in early lower secondary chemistry education in Germany. This most current example also follows the above-mentioned suggestions for reorganizing lab-work. The lesson plan seeks to motivate students in the use of the cooperative mode when performing experiments. It centers around the chemical reactions of sugar and encourages learners to work in a self-regulated and self-organized fashion. All prescribed student activities are based on inquiry-oriented tasks. The planning, preparation, and evaluation of the experiment thus become a cooperative student activity, which includes the documentation of and learning about the theory behind the actual experiments. Assessment is also carried out using a cooperative mode, which is based on the production of posters. The lesson plan is described briefly and experiences taken from teacher and student feedback are also discussed.

From the roots towards a learning company approach for chemistry education

The basic idea for the "learning company" (or "learning office") stems from the field of vocational education. Described in e.g. Pätzold and Lang (1999), learning companies are didactically constructed classroom structures, analogous to existing or "ideal" companies. The aim of this structure in vocational education is to provide a simulation of business-based practical, profession-oriented tasks in the chemistry classroom. The objective of this approach is to aid students' learning by building upon a model. This model is based on pre-existing or idealized companies and includes aspects like how processes in a company actually occur, how businesses are typically structured, or how differing tasks within a company are linked by cause-effect relationships to one another, to the economy, and also to the environment. For it to be successful, this type of learning necessarily must incorporate various aspects of functional cooperation within and between the company's different departments and/or individuals. It therefore provides an opportunity to become an intrinsically motivated cooperative learning experience. In German vocational education, such learning companies and related instructional structures have become increasingly common and also widely implemented in recent years. However, one might ask whether such structures and objectives really match the objectives of secondary chemistry education in regular schools. Skepticism might arise - apart from all other objectives - as to whether or not teaching based on how businesses and industrial structure function should be included in normal, non-vocational secondary chemistry classes.

Nevertheless, some year ago a group of teachers considered the learning company idea to have the necessary potential to promote intrinsic cooperative learning activities in the chemistry classroom. They have been working in a Participatory Action Research, short PAR, (Eilks & Ralle, 2002) project for ten years now, based upon a large amount of work in different cooperative settings in lower and upper secondary chemistry classes in Germany (Eilks, 2003; 2007b). Four years ago, the group decided to look at the learning company approach and to develop it specifically within the chemistry domain. Within such PAR projects practicing teachers and university researchers from science education collaboratively design and research lesson plans using a cyclical process of development, testing, evaluation and reflection (Eilks & Ralle, 2002). The group working on the current project decided to link the approach's inherently different classroom organization structure with a different philosophy of introducing students' hands-on lab activities. They wished to shift learners' actions towards more openness

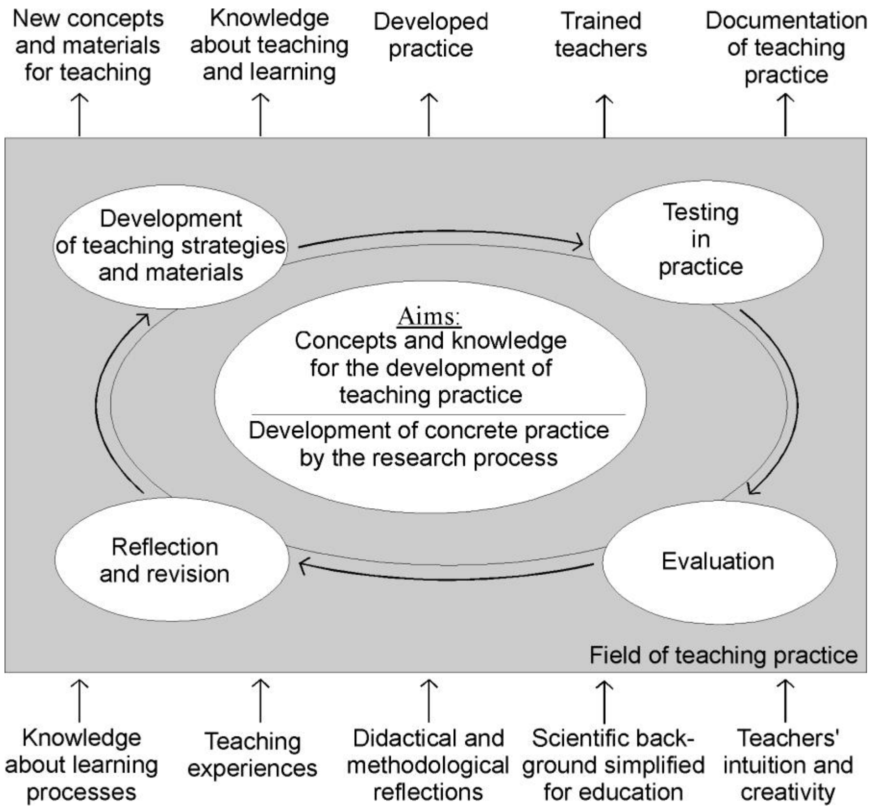

Figure 1. Participatory Action Research in chemistry education (Eilks & Ralle, 2002)

and self-regulation concerning lab-work tasks. This idea was promoted by the accompanying chemistry educator from the university, who thoroughly acquainted the participating teachers with a school project, which had been awarded by the CEFIC Science Education Award in 1999 (CEFIC, 1999). In the CEFIC project, open tasks had been used to promote cooperative learning in the activities of the learner groups.

At the outset, the CEFIC project appeared to be highly unique and hardly transferable into the regular chemistry classroom. Nevertheless, the group emphasized that it was possible to take just some of the basic ideas from the CEFIC project and to develop further useful examples under regular teaching conditions in secondary schools. An initial learning company lesson plan based on acid-base-chemistry was cyclically designed, and then tested for tenth grade chemistry pupils in 2004-5 (Witteck & Eilks, 2006). The objective was to combine all relevant aspects of the respective syllabus parts into one learning company lesson plan, which contained both theoretical and hands-on aspects. The teaching methods selected intended to aid the pupils in performing all necessary learning steps on their own, based on small learning groups. Lessons started with open-ended tasks: goal-oriented "work orders" sent from the manager in the learning company (the teacher) to his departments (the student groups).

Classroom observations and teacher feedback showed that the acid-base learning company represented an amazing change evidencing great potential. In the teachers' opinion, their students achieved unanticipatedly good results as compared to the teachers' predictions before testing the lesson – and the pupils had managed this on their own. The teachers described very high levels of student motivation, enormously self-regulated and successful student activity, and admirable cognitive achievement. Pupil feedback supported the teachers' view. The students responded to the lesson plan very positively concerning the cooperative atmosphere, the open and challenging tasks, and the freedom to follow their own ideas and interests (Witteck & Eilks, 2006). This led the teacher group to the question of whether such an open approach is also applicable to other domains of secondary chemistry teaching, i.e. for younger students. Thus, a second example was developed for younger pupils dealing with methods of separating matter in introductory chemistry education. It's development and testing supported the positive tendencies observed in the first example (Witteck, Most, Kienast, & Eilks, 2007). Finally, the teachers from the group managed to implement both learning companies in a textbook series specifically for lower secondary chemistry teaching (e.g. Eilks, 2007a) and therefore decided to work on more examples like these two.

Method of development

The lesson plan described below was developed in a project of Participatory Action Research (PAR; Eilks & Ralle, 2002; Fig. 1). The group of about 10 teachers had existed for about eight years prior to working on this example (Eilks, 2003; 2007b). The research group has been accompanied by chemistry educators for the University of Bremen, Germany since its inception, and meets roughly every four weeks for one afternoon, when lesson plans are developed and feedback is discussed. The entire process of structuring the lesson plan and respective materials is cyclical, and each of the cycles consists of development, testing, evaluation and reflection. Structuring this particular lesson plan took place over a period of about a year. The structuring was supported through aid from a university graduate student (KB) and was led primarily by one practitioner (TW) from the PAR group.

The lesson plan was actively tested by various members of the PAR group. The first cycle of testing accompanied the final steps of structuring the lesson plan. Later restructuring cycles with other learning groups then occurred, carried with a lag time ranging from a few months up to about a year. Nevertheless, all learner groups were taught using almost an identical lesson plan and working materials.

The teachers' considerations were recorded in open group discussions during the regular PAR group meetings. Additional data came from a combination of an open- and a Likert-type questionnaire, which asked for the students' considerations and criticisms. The pupils were first asked to evaluate which aspects of the lesson plan were important enough to be mentioned (from the students' viewpoint) - either in a positive or a negative sense - in an open questionnaire. After this, a Likert questionnaire was used to gather information on those points considered important by the teachers and researchers. The questionnaires were structured similarly to those used in Leerhoff and Eilks (2005), Witteck, Most, Leerhoff, and Eilks (2004), Witteck and Eilks (2005b), or concerning the learning company in Witteck and Eilks (2006), or Witteck, Most, Kienast, and Eilks (2007).

Data on the students' reflections was collected as a non-representative case from four different learning groups (three in grade 8, one in grade 7) with a total of 88 students in two of the German countries.

Open experimentation on phenomena of chemical reactions: Sabine Sweet & Co.

In German chemistry teaching, chemical reactions are introduced for the first time at the end of the first (or early in the second) year of chemistry lessons, mainly in 7-8th grade with an age range from 12-14. The

Table 1: Overview of the 'departments' in Sabine Sweet & Co.

Department	Open task	Potential solution
Producing artificial honey	Our stock of artificial honey has shrunk significantly. Our customers are already complaining about shortages, but they have also criticized the standard product because it contains different preservatives. Your department's task is to develop a recipe for producing artificial honey made exclusively from sugar and a limited number of other natural compounds.	5g sugar is dissolved in 10mL water. The mixture is heated to 80°C. 1mL of citric acid solution is added and the mixture stirred for 15 minutes. After the mixture has cooled, the product of glucose, fructose and water smells tastes and appears like honey.
Producing caramel	The janitors have told you that a water leak in your caramel production department has lead to corrosion. Your task is to research the formation of caramel to determine whether water is set free during the reaction. Examine the relationship between the masses of reactants and products found in caramel formation. Additionally, please find a way to produce 'caramel coloring' a brown agent used to coloring foodstuffs.	10g of sugar are heated in a beaker until the mass starts to turn brown. The evaporating vapors are condensed on a cold glass and tested for water content. The Law of Conservation of Mass is checked by repeating the experiment in a stoppered Erlenmeyer flask with a glass tube connected to a balloon. The entire apparatus is weighed before and after the reaction.
Getting heat energy from sugar	Rising energy prices have management wondering if sugar can be burned for heat energy. Unfortunately, sugar does not burn easily. Your department's task is to find a way to burn sugar with a flame to extract heat energy from it.	Sugar can only be ignited by a flame if the right catalyst is present. Iron salts in the ashes of plants work well as a catalyst.
Fermentation of sugar	The company needs alcohol to fill its candies. Due to cost effectiveness we intend to produce our own alcohol from sugar. Research and develop a procedure for showing the formation of alcohol.	10g of sugar and 20g baker's yeast are added to 100mL of water at 30°C. The products formed are tested for carbon dioxide using lime water and a digital alcohol test is applied.
Using bio-catalysis	Regular sugar (saccharine) is a problem for diabetics. Other forms of sugar (i.e. fructose) are less problematic. Fructose can be made from saccharine. Research and develop a procedure for showing the formation of fructose from saccharine.	Some acid is added to a solution of sugar. After a short time, fructose formation can be proven using a fructose test strip.
A mirror with the help of sugar	Classical procedures for producing mirrors have made use of special kinds of sugar. Evaluate the procedure. Research and develop a procedure showing the process of making a sugar mirror.	2,5mL of silver nitrate solution are placed in a glass tube. A drop of ammonia is added. Then sodium hydroxide and glucose are added and slightly heated. Silver deposits on the glass.

curriculum states that students must learn that chemical reactions are a change from one kind of substance into another. To understand chemical reactions on the phenomenological level, the students need to learn how to recognize chemical reactions, to be able to differentiate them from purely physical changes, and to learn about different attributes connected with chemical reactions.

The standard example used to introduce chemical reactions in German chemistry curricula is burning a candle. Different reactions between wax, wood and different metals with oxygen are also discussed in most cases. Alternative examples can be selected using different substances from the chemistry laboratory or the household. One very motivating and multifunctional compound in this respect is sugar. Sugar undergoes many different reactions, thus allowing for a broad range of different phenomena connected to chemical change. This example was operationally used by the PAR group to develop a learning company called Sabine Sweet & Co. (in German: Sabine Süß & Co.), a fictitious company absolutely addicted to any form of business, which deals with sugar (saccharose).

After an initial introduction on the general definition of a chemical reaction using the candle experiment, the students are divided into small groups ("departments"), each composed of 4-5 children including a thorough mix of high-achievers and slower learners. Each group receives department I.D. tags upon which they can write their names. With respect to pupils' foreknowledge in cooperative learning, the less experienced groups are asked to elect a speaker, materials collector, time manager, minute taker and public relations person. Such personal denominations are valuable, especially for young or untrained groups, for avoiding the difficulty that only a few of the students might actually perform the work.

The students receive their tasks as a group through "work orders". These work orders are written as a business letter and contain instructions for the task at hand listing the chemicals and equipment available for the group. In addition, each group receives both an identical list of questions about the basic theories of the respective topic and further questions concerning its own special field of interest. Later on, computer resources and textbooks are provided to help the students solve their tasks and to answer these questions. One of the computer resources is a specially structured HTML-environment containing all of the necessary information needed by the students to solve their assignments, but without giving a too detailed solution and explanation. However, the learning environment does contain small videos from different experiments and phenomena and animations of the particle level. The list of questions and their degree of difficulty can be also used to adjust the lesson plan to a specific group's learning capabilities and pre-knowledge. Table 1 gives an overview of the six different departments, their tasks and some potential solutions. The complete teaching materials in German can be found in Beck, Witteck, and Eilks (2009).

Before beginning with lab-work, the students are given 1-2 lesson periods (45. min. each) of preparation time for their experiments. Should the students already be adept enough to find potential solutions without any help, they can initially be asked to make their proposal without additional material. Otherwise, the computer resources, textbooks, or the teacher can provide help. If no computer resources are available, hard copies of the learning environment, more textbooks and relevant working materials can be provided to the students. It is entirely possible that some of the pupils' plans might end up having to be scrapped, since their execution might not lead to the learners' desired goal. The independent planning phase of the experiment therefore becomes more important than the actual experimentation itself. The students can work creatively and freely develop themselves and their ideas. It is a very special event, if and when their independent planning actually leads to successful results.

Before starting the experiment, the students must explain their plans to the teacher and ask for a "green light" to start. This assessment must also address any relevant questions of safety regulations and risk assessment. After receiving an all-clear from the teacher, the students have a total of another 1-2 lesson periods to carry out their experiments, including careful documentation of all their activities. It is very helpful at this point, if access to the computer-based learning environment is also available. If a proposed solution doesn't work, the teacher can provide the pupils with ideas or - in the worst-case scenario - give them a descriptive procedure for the experiment.

Next, the lab-work and answering of all questions on the work sheets should be carefully diagrammed in the form of a poster, so that students in the various other departments can also understand and absorb both the content and the experimental results presented. Other forms of presentation might be also used, e.g. presentations using transparencies or PowerPoint.

In the end phase, each of the departments presents its experimental results to the whole class. The students receive another worksheet, upon which they must document and evaluate the results of the other departments. They have also the opportunity to actively review things which they either did not understand the first time around, or where they still have questions about the experimental procedures or end results.

Experiences and evaluation

In their feedback, the teachers considered this learning company to be another example of a highly motivating framework for learning chemistry. From the classroom observations, the students were seen as extremely curious, even during the initial presentation of the brand-new learning company idea. They quickly became engaged in a competition among themselves, beginning their work with a clear focus on the problems to be solved. The teachers interpreted this to mean that such a framework offers learners a quasi-authentic and very challenging learning situation. According to the teachers, their students seemed to directly identify themselves with their specific group or department.

One of the most important impressions mentioned by the teachers was the intense, on-task activity taking place among their pupils. The learners were very concerned with the question of how to effectively structure promising experimental activities to solve their given task. In nearly all of the cases, the groups found a way to solve its problems. However, their strategies differed widely. The attempts ranged from purely trial-and-error approaches to well-thought-out, meticulously planned procedures. With respect to the students' foreknowledge and cognitive abilities, inductive and deductive strategies of problem-solving were applied, and sometimes explicitly negotiated. Some groups even mixed both approaches and purposely shifted their methods due to discussion and reflection.

Table 2. Results from the Likert questionnaire, 4 step (1 = agree; 4 = don't agree), 4 learning groups, N=88, average mean score of the groups, standard deviation and interpretation of support for the respective statement

	Item	mean	σ	support
1	Within the learning company I could work more autonomously than in my other classes.	1,72	0,23	++
2	I missed the direct support and control during every step of my work by the teacher.	2,55	0,11	o
3	Within the learning company I worked much more intensely than in my other classes.	2,03	0,37	+
4	I like it better, if the teacher explains an issue with the whole class rather than learning in small groups.	2,88	0,20	-
5	I believe that I learned a lot in the learning company.	1,73	0,31	++
6	I don't like to work in a learning company because my work depends too much on my classmates.	3,03	0,34	--
7	I considered working in the learning company to be confusing.	2,97	0,33	-
8	I like the learning company because I was asked to work together with my classmates	1,53	0,26	++
9	It was difficult for us to organize our work in the small groups.	2,64	0,35	-
10	I believe that I learned a lot using the computer environment.	2,35	0,05	+
11	I like the learning company because we were allowed to do our experiments autonomously in small groups.	1,33	0,16	++
12	I liked the learning company because we were allowed to do experiments without prescribed guide.	1,86	0,22	++
13	The use of alternative methods makes the lessons more fun and less boring.	1,76	0,25	++

The teachers considered it advantageous to include openness where it concerned pupils' selection, sequencing and weighing of their own activities. The learners were free to repeatedly shift their focus between hands-on activities, the search for additional information in the multi-media learning environment, Internet or textbooks, and phases of discussion and negotiation. Such networked activity dealing with theoretical information, practical work, communication, was described as a total turnabout from the teachers' past experiences and fulfilled the need for change as outlined by Nakleh et al. (2002). The teachers were amazed at the different atmosphere during the lab-work. They also praised the increased levels of pupil self-reflection, since this had been outlined as a promoting factor for effective learning in the lab by Gunstone and Champagne (1990). This study had advocated more emphasis on student activity in the planning and evaluating phases of experiments. Also, the results from the learning groups – their minutes, posters, slides and presentations – more than fulfilled the pre-test expectations stated by the teachers for that age level. The only difficulties observed concerned some of the learning group compositions and single steps in the entire process.

The positive evaluations of the teachers are supported by the students' answers in both questionnaires. Although the open questionnaires give positive images and present ideas for further improvement of the teaching approach in detail, they cannot give a full overview of all of the students' considerations. However, the Likert items can provide such insight. In the Likert questionnaires, the students recognized and appreciated the autonomous atmosphere while working in small groups, with only small differences occurring between the learning groups. The autonomous experimentation in small groups and cooperation with classmates (Table 2, items 8, 11 and 6) were singled out for especially positive remarks. Nevertheless, the learners also very much agreed that the freedom to be allowed to work without a "recipe" and the opportunity to work more autonomously (items 1 and 12) were both very positive developments. On the other hand, the students stated that they didn't miss guidance (items 2, 7 and 9), nor would they prefer more teacher-centeredness in the learning process (item 4).

Overall, the students had the feeling that they had learned a lot (item 5) and worked quite intensely (item 3), even though they viewed the learning parts centering around the computer to be less effective (item 10). Despite these aspects, the overall comments that the lesson plan had led to a positive outlook through the use of respective methods (item 13) is completely in line with the examples described in Witteck and Eilks (2006) and Witteck, Most, Kienast, and Eilks (2007).

CONCLUSIONS

The lesson plans described here attempts to refine pathways to cooperative, inquiry-oriented learning, including lab activities, by adopting the learning company approach. The teaching unit evidenced high potential for promoting active chemistry learning, thus confirming similar findings in other examples (Witteck & Eilks, 2006; Witteck, Most, Kienast, & Eilks, 2007). Such educational changes in the practice of chemistry lab-work instruction seem to offer potential which leads to a different type of learning culture. This new culture can be described as self-dictated, self-organized, self-responsible learning. We believe that a cooperative learning environment approach for solving open experimental tasks shows great promise for overcoming the lack of student motivation, which is often reported in chemistry classrooms. It also seems that such learning forms not only do not decrease cognitive achievement, but also clearly increase student skills in various strategies of problem-solving, negotiation, and presentation relevant to scientific inquiry with respect to methodological questions. Together with the previously published lesson plans on acid-base-chemistry and methods of separating matter (Witteck & Eilks, 2006; Witteck, Most, Kienast & Eilks, 2007), we consider the processes provoked by the learning company approach to be a valuable tool for aiding students. It helps learners address the issue of familiarizing themselves with typical paths of scientific inquiry as an integral part of their growing personal knowledge about the nature of science. Such examples can help to enrich both the methodology and pedagogy of modern chemistry education through the use of more frequent, inquiry-based experiments (Hofstein & Lunetta, 1982; Gunstone & Champagne, 1990; Kipnis & Hofstein, 2007). They also can serve as a support in implementing measures systematically in cooperative modes of chemistry learning and instruction (Nakleh et al., 2002).

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