CHEMISTRY EDUCATION: RESEARCH AND PRACTICE
2004, Vol. 5, No. 2, pp. 111-126

Theme Issue:
Chemistry and Environmental Education
RESEARCH REPORT (EMPIRICAL STUDY)

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LEARNING BEYOND SCHOOL: ESTABLISHING A LABORATORY FOR SUSTAINABLE EDUCATION

Received 1 April 2004; revised 26 May 2004; accepted 27 May 2004

ABSTRACT. The paper is about a research and development project ("Praxisforschung") devoted to the design, realisation and evaluation of a laboratory for sustainable education. It has been established through a cooperation of a State Academy for Technology Assessment, a Museum for Technology and Labour and a University of Education as an external learning centre for schools. It offers a learning environment that can be adapted to the needs of students grade 1 to 10, devoted to the topic "climate change". The pedagogic concept is based on self-directed learning of students combined with a tutorial system supported by the University of Education Heidelberg. Single visits of classes and long-term cooperations with schools are possible. Experimental activities in the laboratory are assessed by student questionnaires. All aspects of practical work in the laboratory are highy appreciated by students, irrespective of age or gender. The reason most often given for liking the laboratory was "one had to think and work on one´s own". The laboratory is an element in a systemic approach to teaching for sustainability. [*Chem. Educ. Res. Pract.*: 2004, *5*, 111-126]

INTRODUCTION

In the year 2000 the Academy for Technology Assessement of the state of Baden-Württemberg (Germany) presented a status report on sustainable development (Renn, León, & Clar, 2000). The academy had identified "indicators" for sustainable development in the fields of human resources and environment (Pfister & Renn, 1996). They were chosen according to the concept of OECD (Anonymous, 1994) and based on available data in the state of Baden-Württemberg. For example, indicators for human resources are knowledge available in individuals and knowledge available in institutions; indicators for environment are air quality, water quality, biological diversity etc. In the report immediate need for action was declared necessary in various fields, the most important one being climate stability, i.e. reduction of CO_2 emissions, since there is a commitment of the state to reduce emissions by 25% by the end of the year 2005 (reference value: emissions 1990).

In order to actively support the state's goals of sustainable development three institutions agreed upon a professional partnership: the University of Education Heidelberg (PH), the Academy for Technology Assessment of the State of Baden-Württemberg at Stuttgart (TA-Akademie), and the State Museum for Technology and Labour at Mannheim (LTA). They decided to established a "workshop for the future" (*Zukunftswerkstatt*), built up of three main components: (1) a discussion forum for the youth (aged >16); (2) a discussion forum for adults, i.e. citizens of the region; and (3) a laboratory for experimental activities of students aged 5 through 16. All three activities were devoted to deal with the issue "climate change and noise pollution" in the Rhein-Neckar-Region, a centre for industry, research and education.

The TA-Akademie has great experience in participatory technology assessment and developed a concept for so called discussion fora for students and experts, discussing, debating and finally proposing decisions on real problems of technological development in the state (Baur, Müller, & Schulze-Tammena, 1999). The LTA has a concept of displaying the technological development of the Rhein-Neckar-Region in its social context. The PH recently has founded a science-technology-society institute devoted to research and development in integrated teaching of natural sciences in an STS-context.

All of these activities match nicely the superordinate goals of the state's education system such as "the linking-up of social life, technology, nature, natural sciences, own personality..", and "the ability of students to take part in social discourse" in matters of science and technology which are stressed in the general description of the State's curricula (cf. http://www.bildungsstandards-bw.de/).

Also, the within the ongoing revision of school curricula *integrated subjects* such as Natural Sciences and Technology (in the STS- or nature-of-science context respectively) will be introduced. Schools are supposed to develop individual specific *profiles* in their mathematics and natural sciences courses in the year 2004, with prescribed interdisciplinary approaches to teaching. Team teaching across subject boundaries is encouraged by the authorities (cf. http://www.bildungsstandards-bw.de/).

A network of experts from research, industries, technology assessment and administration in the region was available to offer support in any question connected to the project. In this paper the theoretical considerations, the practical realisation and the evaluation of the laboratory will be presented.

THEORETICAL CONSIDERATIONS FOR ESTABLISHING A LABORATORY AND DESIGNING LEARNING ACTIVITIES

As a theoretical basis for planning laboratory activities, an interdisciplinary attempt to define "understanding science" was considered aiming at preparing school graduates for their active role as responsible citizens in a participatory democratic society. Concepts of pedagogy, didactics of natural sciences, technology assessment and the new research field "ethics in the sciences" have been amalgamated into the following definition. Individuals having a fully developed "understanding of science" are able to:

- recognise science as a methodical endeavour for knowledge **and** a social system[1] for acting;
- recognise problems in the field of new technologies as interdisciplinary problems which could be solved only in an interdisciplinary effort;
- identify and take into account the difference between technological approach and problem orientated approach for solving problems[2];
- use - besides factual and instrumental knowledge - purposefully ethics as a means of reflection (Schallies, Wellensiek, & Lembens 2002).

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[1] Research is taking place in organisations, involving people who have to agree on research topics, who interpret and give meaning to experimental results, thus forming a social system for acting and valuing

[2] In a technological approach a certain technology is taken as given, and its specific advantages/ disadvantages are considered. In a problem-oriented approach all technologies available are considered, and which will be the best for the purpose.

This definition unites concepts from different disciplines: (1) concepts related to the teaching of the epistemology of science and STES approaches in science teaching, aiming at “informed views and positions” (Ben-Chaim & Zoller, 1991; Ebenezer & Zoller, 1993), “balanced views” (Ramsey, 1993), “informed judgments” (Riggs, 1990), “thoughtful decisions” (Aikenhead, 1985); (2) the considerations of pedagogy – which go back to Kohlberg - that judgements are made contingent on the moral development of individuals (Brumlik, 1999); and (3) the concept of **ethics in the sciences** as a problem-orientated approach to solve real life problems (Wimmer, 1999). Conway and Riggs (1994) have postulated stages for understanding and valuing in technology. These, we believe, can be interpreted as being contents of Selman´s more general theory of social understanding and perspective taking (Schallies & Wellensiek, 1995). According to this theory, students could reach higher stages of cognition only through active learning processes in a social and material environment that offers a range of possibilities for decision-making, action-taking and valuing. These considerations are in agreement with projects that propose holistic, active and participatory approaches (Tilbury & Turner, 1997). Concepts for teaching environmental issues in Switzerland also stress the entity of informed judgements and action-taking in a social context (Kyburz-Graber & And, 1997; Kyburz-Graber & Robottom, 1999; Kyburz-Graber & Högger, 2000; Robottom & Kyburz-Graber, 2000). Given demanding tasks and an open learning environment, students might develop such competencies, which could also be defined as competencies for critical and reflective thinking (Zoller, 2000).

Another line of reasoning goes back to Huckle and Sterling (1996). They have defined parameters that are characteristic for sustainable education:

Contextual	In touch with the real world, particularly sustainability issues.
Innovative	Drawing inspiration from new thinking and practice in a variety of fields including the educational field.
Focused	Concentration on social development, human ecology, equity and futures.
Holistic	Relating to the learning needs of whole persons and groups.
Multi- and transdisciplinary	Emphasising on new territory between the disciplines.
Empowering	An engaged and participatory process.
Critical	Ideologically aware and deconstructive.
Balancing	Embracing cognitive and affective, objective and subjective, material and spiritual, personal and collective, etc.
Systemic	Paying attention to systemic awareness of relationships, flows, feedbacks, and pattern.
Ethical	Extending the boundaries of care and concern from the personal and the now.
Purposive	Critically nurturing sustainability values with the intention to assist healthy change.
Inclusive	Encompassing all persons, in all areas of life and extending throughout their lifetimes.

Finally, considering the theory of Deci and Ryan (2000), there are primary psychological needs to be satisfied in a learning environment that helps to build up an intrinsic motivation: individuals want to experience (1) competency, i.e. through control of actions and their outcomes; (2) self-determination of actions; and (3) social integration (affiliation). In order to support self-directed learning students must be given an active part in planning of learning activities, or learning processes must be organised such that students necessarily have to plan and organise their course of action independently.

Offering laboratory activities in a science museum are not new (Finson & Enochs, 1987), and many attempts have been made recently to establish laboratory activities for school children at universities, as well in attempts to promote public understanding of sciences and humanities in Germany (overview at http://pc1.uni-bielefeld.de/~jenett/bmbf/bmbf-mitmlab-d.html) and elsewhere (Ramey-Gassert, 1997). In order to capitalize on accumulated experience, the project partners have visited corresponding establishments like the Technorama in Winterthur/Switzerland, and have made an inventory of initiatives for science centres in Europe (Baur, Müller, Renn, & Mack, 2000) and also considered studies evaluating hands-on activities offered to visitors in science centres (Anderson, 1999; Barriault, 1999). Usually, surface phenomena are measured: how many persons are attracted by a specific exhibit? For how long are they attracted? How are they dealing with exhibits or experiments? Usually, children and young persons trigger an experiment, there attention is drawn to the observed phenomenon for a short period of time, and immediately after devoted to the next exhibit which is casually triggered as well ("hit and run behaviour")(Barriault, 1999).

From observations in science centres three underlying ways of behaviour have been identified (Barriault, 1999): (1) When a person executes an activity, watches the activity of another person or turns to other experimenters or visitors with a question or asks for support for own activities, this is defined as "initiation behaviour". (2) When a person executes an activity or experiment repeatedly while voicing emotional feelings about these activities, this is defined as "transition behaviour". (3) When a person refers to previous experience while executing an activity, when a person seeks information or discusses information relevant to the activity with others, this is defined as "break-through behaviour". At this stage, a person starts to investigate independently, testing variables, making comparisons, gathering more information.

A rich learning environment should offer activities supporting such break-through behaviour, and in order to realise such an environment we believe support of student's activities by tutors is essential. The challenge is to bridge the gap between an instruction model of teaching that is product-oriented (knowledge of facts and skills) and an educational model that is process-oriented (the dynamic process of generating knowledge for understanding). As a prerequisite, a learning environment would be required that involves learners into actively planning their own learning process, or the learning process planned by the teacher is such a way that learners have to plan independently their ways of going-on (Arnold & Schüßler, 1998).

DESIGNING A LABORATORY FOR SUSTAINABLE EDUCATION

A mixed workgroup was established. Members were educationalists, researchers in science education, representatives from industry, science teachers from elementary, junior high, and high schools, two 11th grade students, and representatives from the TA-Akademie, the LTA, and the author's STS-institute. The task was to develop a concept for the laboratory, based on a developmental concept, and differentiated for elementary students grades 1-4, and secondary students grades 5-10. The laboratory was to be installed in the technical museum of Mannheim, open to all schools of the region (N= 256) and serving as an external learning centre, offering experimental set-ups to investigate "climate" and "noise". Students´ activities in the laboratory were to be supported by students from the University of Education Heidelberg, acting as tutors and at the same time getting a professional training-on-the-job as advisers for pupils´ learning activities.

It was decided to integrate students´ views into the detailed planning of the set-up and activities in the laboratory, and gather their previous knowledge on “climate”. Also, we would like to know what students imagined about the equipment in such a laboratory. It was decided to introduce the topic “climate” to students through a personal experience in a “greenhouse”, representing the entrance into the laboratory. The intention was to stimulate “research questions” with respect to climate change. The greenhouse was to represent the plant-growth in the Rhein-Neckar-Region in the year 2050, due to climatic change.

The task of designing a greenhouse was taken up by a project group of 6 students grade 7 and their teacher as an extra-curricular activity at school. They were given the task to find out what will be the climate in the Heidelberg-Mannheim region in the year 2050, what will be the corresponding flora, and how could the consequences of climatic change be represented in a greenhouse (Lembens, 2002).

Integrating students´ views into the design of the laboratory

Our research methodology could be defined as “Praxisforschung”. In German terminology this type of research is in part case study, in part developmental research. It makes use of both classical empirical research methods and hermeneutic interpretative methods (Popp, 2001). Praxisforschung is aiming at change through active participation of persons and groups involved in a specific educational system, i.e. researchers take an active role in changing and evaluating the outcomes of specific measures taken. Praxisforschung requires participation and dialogue, setting of common goals, putting measures into practice and assessment of outcomes. Representatives from research, the education system and those persons that are working in the field that is to be changed are involved. Praxisforschung is always social research as well. The open question is which aspects of research could be controlled in a methodical way and will be accepted.

A preliminary investigation was carried out with students grades 1-4 from a primary school (N=92). Students of this age were interviewed. Semi-structured interviews were transcribed and statements categorized. A questionnaire for a preliminary investigation of students´ opinion grades 5-13 was designed by the student members of the work group (Torben Müller, Sabrina Obers), who also carried out the follow-up evaluation study at their school. It consisted of a mixture of open- and closed-ended questions. Examples: “What topics would you like to deal with if you were responsible for designing a workshop for the future?” (Choose from a list; tick the 4 most important items). “What is of special interest to you?” (Choose from a list). ”Have you been confronted with the topic “climate” in your daily life already?” “What have you done, personally, for a good climate?”

RESULTS

Primary students´ views (grades 1-4) about laboratory activities and their previous knowledge about “climate”

From the point of view of students the following activities were of greatest importance: doing project work with other children; trying out things on ones own; using computers and Internet to find information. Also, they would expect to have signs in the laboratory explaining everything, and carry out activities like watching films or preparing articles for newspapers.

Most of the students (74.5%) in primary school (N= 92) had not heard the term “greenhouse effect”, yet a small portion (11.8%) had heard about it, but could not explain it, some (7.8%) described a greenhouse in order to explain the term, wrong explanations were given by 4.9% and only 1% was able to explain the greenhouse effect correctly.

Secondary students´ views (grades 5-13) about topics to deal with in a "workshop for the future"

Chosen from a list, supply of energy (51%), greenhouse effect and ozone depletion (43%), alternative energies (41%), and change of climate (34%) rank very high, only surpassed by illnesses of modern civilisations (58%). World of work (35%), change of society (30%), population change (25%) and globalisation (21%) come next. Noise pollution is not ticked.

From the point of view of students, Internet access (56%), opportunities to try-out something (54%), teamwork (52%), watching video films (51%), self-directed research (45%), experiencing phenomena (43%), displaying models (41%), consulting experts (38%), publishing findings or ideas (37%), working with experts (36%), doing project work (35%), organizing discussion groups (27%), taking products home (26%) or use of multimedia and literature are important aspects of a workshop for the future.

Younger students have come across the topic "climate" mainly at school or through the media, whereas older students have more differentiated ways of access to the topic (see Table 1).

TABLE 1. *Sources for secondary students´ familiarity with the topic "climate" in everyday life. Open-ended question; answers were categorized; more than one answer was possible. Percentage of total answers.*

	age 11-14	15-19
school	52.4	22.9
weather phenomena	11.2	27.3
media (TV, print media)	24.6	15.3
at home	-	1.1
outdoor activities (skiing etc)	3.2	1.1
discussions	-	1.1
change of world climate	4.3	9.2
ozone depletion	3.3	12.0
"green organisations"	1.1	-

In response to the question "What personal action do you have already taken to improve climate quality?" students mentioned "environmentally friendly" transport (bicycle, walking, public transport) (Table 2):

TABLE 2. *Secondary students´ ways of taking personal action to improve "climate". Open-ended question; answers were categorized; more than one answer was possible. Percentage of total answers.*

	age 11-14	age 15-19
being a non-smoker	2.7	6.4
using public transport	13.5	36.0
use bicycle / walking	59.5	32.5
save energy	2.7	7.5
avoid products made of chlorofluorocarbons	10.8	4.5
minimize waste/ practise waste separation / recycling	5.4	9.0

In response to the question “Should a workshop for the future prepare normal classes, complement normal classes or be independent of work at school?”, students definitively voted for the complementary aspect of extracurricular activities (Table 3).

TABLE 3. *Secondary students´ preferences for extracurricular activities in a workshop for the future. Percentage of total answers.*

age group	prepare classes	complement classes	be independent, separate
11-13	3.0	75.9	21.1
14-16	20.8	63.2	16.0
17-19	2.8	84.0	13.2

Interpretation

From the preliminary investigation it is apparent that elementary students have practically no previous knowledge about climate change. They are interested in the social aspects of laboratory activities like working in groups. They also want to carry out activities independently, finding information on their own by the use of internet, getting information about the laboratory equipment by means of printed explanations. From this we concluded that for primary students activities in the laboratory should be devoted to basic phenomena and guided discovery.

Secondary students chose the appropriate catch words like greenhouse effect and ozone depletion from a list. They also have some vague connotations that change of climate has something to do with human activities like transport. Making use of bicycles and public transport is a way of behaving “climate friendly”. Some references to chemical aspects like avoiding products made of chlorofluorocarbons or “ozone depletion” were made. We consider the mentioning of such terms to be “surface phenomena”, lacking any deeper insight into the matter. In support of this assumption we may point that these topics are frequently being discussed in the media. Also, students did not make any definite connection to “climate gases” in the atmosphere like carbon dioxide or methane, nor to the physico-chemical basis of the natural greenhouse effect, nor to the combustion of fossil energies.

Interestingly, secondary students voted strongly for extracurricular laboratory activities being complementary to normal classes. This is especially true for the older secondary students who approach the final school examinations. We interpret this as a wish to improve on the knowledge base, and an indicator that normal classes are inadequate with respect to laboratory activities. From own investigation in the region we know that students lack experimental activities at school.

From these findings we have concluded that all activities offered to classes in the laboratory should definitely be coordinated with previous classroom work and curriculum. Since the student population coming to the laboratory will be very heterogeneous in age, previous knowledge, experimental skills, the experimental design offered should not be fixed, but variable, corresponding to students´ previous knowledge and supported by tutors.

Realisation of a greenhouse to demonstrate the climate of the future

A project group of 6 students grade 7 and their teacher took over the demanding task of making students feel the climate of the future of the Rhine-Neckar-Region as a physical experience in a greenhouse. First of all they had to find out relevant information on local and global causal relationships that influence weather and climate, and structure it. They decided to try solving the following questions: “What is climate dependant on?” “How can one measure climate?” “What is a greenhouse effect?” “What are climate relevant gases, and how do they come into existence?" They soon found out that there are various sources of information, often with contradicting statements. It was irritating for the students to find different interpretations of the same data by different researchers, coming to different conclusions.

They decided to interview real experts at the Institute for Environmental Physics (University of Heidelberg). This was arranged. Students had a chance to see the scientists at work, get to know the methods of measuring parameters that constitute climate, see various apparatus in action, and query the scientists about their research questions. Two key statements were made by the scientists: (1) it is not possible to exactly predict the climate in the region in 50 years to come. (2) It is highly probable that the climate in this region will be that of the Mediterranean Sea region, i.e. mild winters and longer lasting summers.

Based on these predictions the students collected information about plants that would grow in such a climate, technical details concerning the construction of a greenhouse and finally decided about definite purchases of a prefabricated greenhouse, plants, substratum for plant growth, making arrangements for a "learning environment" inside the greenhouse. Once again, "experts" had to be consulted as a basis for decision making, and a stock of money provided to carry it all out. Since they had to take care of a learning environment, there was the question what to expect from future visitors as background knowledge. They decided to carry out interviews with adults in the streets and administer a questionnaire to fellow students at school.

After all preparatory steps had been accomplished, the laboratory was established in the science museum on an area of ca. 300 m^2 . The installation was made public by a general mailing to all primary and secondary schools across the Rhine-Neckar-Region, and via the school authorities of the region as well.

Finally, at the opening ceremony of the workshop of the future, the students presented their research findings about the climate of the future in the region, i.e. in the year 2050, explaining their "informed views and posititions" in front of more than 100 guests by means of overhead transparancies, demonstrating the process of learning, and finally the product of their learning as an object: the fully equiped greenhouse (see Figure 1).

FIGURE 1: *Students of a project group and their "product" of learning.*

FIGURE 2: *Grade-9 students preparing experiments to generate electric energy from wind.*

General course of visits to the laboratory

Generally, two ways of making use of the laboratory are open to schools: (1) a single visit in the course of conventional classroom work, making use of the laboratory to complement classroom activities; and (2) a long-term cooperation, where the resources of the laboratory and the network of experts are made available for school project work. An example for a long-term cooperation could be a school project, within which activities are taking place in the laboratory of the workshop for the future and at school in a coordinated fashion.

For single visits, the underlying idea is that students should enter the laboratory with a question, and use the facilities; the instrumental and personal resources to try find answers to their queries. Therefore, there are no fixed experimental procedures prescribed for visiting classes. Instead, in a preceding discussion with tutors, every group has to decide about an individual appropriate "research question", design of experiments, and how to organize carrying out tasks in search of solutions to problems that have been identified. Classes split up into small workgroups, depending on their intentions and particular likings. Each group of 4 to 6 students is given a personal tutor. The task of the tutors is to moderate students´ discussions, help them design experimental set-ups and procedures, support students´ interpretation of outcomes and presentation of results including preparations of posters, give informational input when asked or when necessary. Tutors have received training before and are further trained on the job in the laboratory. The greatest challenge for them is to prompt questions or give open advice that help students´ process of thinking and experimenting, such as "describe more clearly, what you intend to do", "this is an interesting suggestion, try to peruse it" or "check if your new results are true in all cases" (Dubs, 1999).

Teachers would have to make an appointment for a visit of the laboratory well in advance and fill-in a questionnaire about the class, previous knowledge of students, ongoing classroom activities, and purpose of the visit. They were offered a handout with background information, and were asked to prepare their students for the occasion. A session in the laboratory would last for about 2 ½ hours. In-service training courses for teachers have also been offered to support making the external learning environment effective for the education system.

TABLE 4. *Sequence of activities during a visit to the laboratory.*

Reception of visiting class by the team of tutors
Get to know the problems Experience the greenhouse
Verbalizing first reactions Moderated discussion to talk about students´ feelings / experiences and to put in context with the general underlying problems
Presentation of students´ intentions What is the purpose of their visit; what do they want to investigate
Doing "research" at experimental stations Students work in groups; individually supported by a tutor. "Research questions", experimental set-up, results and conclusions have to be put down in a protocol
Presentation of experimental results Students prepare posters of their findings
Collecting and combining results Each group has to present and explain their findings to the plenum. Final discussion

Examples of experimental set-ups offered for self-directed learning activities:

- Generating electric energy from mechanical energy by means of an ergo meter built from a bicycle; plant communities in the year 2050 (greenhouse);
- Carbon dioxide – all-rounder and cause of climatic change: chemical experiments;
- Solar energy and wind energy: experiments for the production of energy, investigating the dependence on relevant parameters (construction kits);
- "Air is not emptiness": making use of air as a means of propelling things (introduction of the climate topic for elementary school children, since gases are not yet understood as matter at this age).

Evaluation of single visits

The evaluation of single visits was carried out by questionnaires and participant observation. The first 5 classes were used as guinea pigs to see if the learning environment of the laboratory was appropriate under *real* conditions, to test the experimental laboratory equipment, coordinate tutor's activities and test the design of the questionnaire. Also, teachers´ advice was asked for after each visit. After these preliminaries, everybody approved a general procedure for visits. Questionnaires were to be employed for all classes. In the following tables the data obtained from questionnaires are displayed. Student questionnaires were filled in immediately at the end of activities in the laboratory.

TABLE 5. *Distribution of students using the laboratory according to age and gender (N=194)*

10	11	12	13	14	15	16	17	18	age
1	4	35	3	4	33	26	4	0	f
0	7	25	2	4	24	21	1	0	m

Students´ opinion of the lab work was enquired by the following questions: *Today, you have occupied yourself with wind energy.* (Or solar energy / or carbon dioxide; three different questionnaires). *Did you have any previous knowledge?* (Tick yes or no). *If yes, where did you get your knowledge from?* (Choose and tick from the list; several answers may be given).

TABLE 6. *Previous knowledge according to topic and gender. Values are given as percentage of students´ answers. Data underlayed in grey are absolute numbers.*

		yes	no	N
climate	m	84.7	15.3	85
	f	92.0	8.0	113
CO_2	m	13	1	14
	f	29	0	29

TABLE 7. *Sources for previous knowledge according to topic and gender. Values are given as percentage of students´ answers; more than one answer was possible. Data underlayed in grey are absolute numbers.*

	climate		CO_2	
	male	female	male	female
chat with parents	22.2	14.4	3	3
chat with friends	22.2	5.8	2	0
lessons at school	70.8	85.6	8	27
media	70.8	44.2	5	6
other	11.1	2.9	2	1

As can be seen from the tables, students estimate that they do have previous knowledge. The most important sources for knowledge are lessons at school and the media. Reasons for being interested in the specific topic were asked for in an open-ended question: *Are you generally interested in the topic?* (Tick yes or no). *In either case: What are the reasons?*

TABLE 8. *Interest according to topic and gender. Values are given as percentage of students´ answers. Data underlayed in grey are absolute numbers.*

		yes	no	no opinion	N
climate	m	79.3	20.7	0.0	87
	f	54.1	41.4	4.5	111
CO_2	m	13	1	0	14
	f	21	7	1	29

Reasons for being interested were categorised and evaluated. Questionnaires obtained from the first 16 visiting classes were evaluated completely in this way. Since no more new aspects or categories came up, "saturation" was assumed. (Theoretical saturation is a term that has been coined by Glaser & Strauss (Glaser & Stauss, 1979) (grounded theory). In the development of the VOSTS-instrument Aikenhead & Ryan (Aikenhead & Ryan, 1992) have adopted this method for the categorization of students´ written statements). Random samples taken from the following 10 classes showed this to be true. Those students, who did not have interest in the topics, thought the topics unimportant or boring, being of no general interest. Students´ opinions about the importance of the respective topic were obtained by the following question: "*Do you think the topic is of fundamental importance?*" (Tick yes or no). *In either case: What are the reasons?*

TABLE 9. *Students´ opinion about the importance of the topics according to gender. Values are given as percentage of students´ answers. Data underlayed in grey are absolute numbers.*

		yes	no	no opinion	N
climate	m	92.0	8.0	0.0	87
	f	86.6	12.5	0.9	111
CO_2	m	13	1	0	14
	f	28	0	0	28

Students reasoning positively with respect to "climate" predominantly mentioned environmental protection and relevance for the future. Also, "it is part of general knowledge" and "it is useful for daily life". There were only few reasons given by those who thought the topics unimportant, just "that it has no relevance to daily life", or that "one cannot change things anyway". Students´ feelings about the experiments were obtained by the following question: *"How did you like it?"* and a Likert-scaling for response. Also, there was an open-ended question asking for argument: *"What exactly did you like or find bad?"*

TABLE 10. *Liking of the experiments according to topic and gender. Values are given as percentage of students´ answers. Data underlayed in grey are absolute numbers.*

		excellent	good	average	not good	not at all
climate	m	28.3	38.7	25.5	6.6	0.9
	f	28.4	54.1	14.9	0.0	2.7
CO_2	m	15	9	5	0	0
	f	12	2	0	0	0

The reason mentioned most frequently for liking the experiments performed (irrespective of topic) were ”one had to think and work on ones own”. Also mentioned (in declining order) were “one could learn a lot”, “one had to find out things on one’s own”, “there was good support from the tutors”, “there were interesting experiments to perform”. Reasons given for not liking the experiments were few and quite divers. Only “in the long run it was boring” was mentioned several times. Since the learning environment was supposed to foster self-directed learning, the following question was asked: *Did you have an opportunity to realise your own ideas for experiments?*

TABLE 11. *Opportunities for self-directed experimental activities according to topic and gender. Values are given as percentage of students answers. Data underlayed in grey are absolute numbers.*

		yes	partly	no	N
climate	m	46.8	39.6	13.5	111
	f	36.0	32.4	9.0	86
CO_2	m	12	2	0	14
	f	13	10	4	27

Reasons for being able to realise own ideas were “good teamwork”, “active individual involvement”, “opportunities for working independently” and “opportunities for trying out different alternatives”. Reasons for not being able to realise one’s own ideas were “lack of good teamwork”, “experiments were set up in advance (by other members of the team)” or “lack of sufficient time”. Also, some apparently had “no ideas of one’s own”.

Finally, students were asked to assess the experimental activities in several aspects (see tables 12, 13) (Likert-type scaling).

Asked for suggestions for improvement, 34.5 % of students stated “leave it as it is”. 21.2 % did not answer and 44.2 % made definite statements which were categorized. They asked for more experiments, more time, better organisation in the museum where the laboratory is situated (better signs in the technical museum giving direction to the laboratory, better informed museum personnel) and even more demanding experimental set-ups.

TABLE 12. *Students´ assessment of experimental activities connected to the topic* ***climate*** *according to gender (ratings in percentage of answers). Scaling from 1 to 5 analogous to grades at school.*

	rating		1	2	3	4	5	rating
being looked after	excellent	f	54,1	29,7	12,6	3,6	0,0	very bad
		m	60,5	29,1	8,1	1,2	1,2	
setting of tasks	comprehensible	f	43,2	35,1	10,8	5,4	5,4	incomprehensible
		m	52,3	34,9	9,3	1,2	2,3	
clarity	clear	f	33,0	37,6	19,3	10,1	0,0	confused
		m	32,6	51,2	12,8	1,2	2,3	
difficulty of tasks	easy	f	37,5	37,5	20,5	0,9	3,6	difficult
		m	44,2	27,9	24,4	2,3	1,2	
handling of apparatus	easy	f	48,2	33,9	11,6	0,9	5,4	difficult
		m	61,6	22,1	11,6	3,5	1,2	
gain of knowledge	excellent	f	40,5	34,2	19,8	2,7	2,7	very bad
		m	52,3	26,7	14,0	3,5	3,5	
do one’s own research	excellent	f	45,5	26,8	17,9	8,0	1,8	very bad
		m	48,8	24,4	11,6	11,6	3,5	

TABLE 13. *Students´ assessment of experimental activities connected to the topic CO_2 according to gender. Scaling from 1 to 5 analogous to grades at school. Ratings in absolute numbers of answers.*

	rating		1	2	3	4	5	rating
being looked after	excellent	f	17	9	2	0	0	very bad
		m	11	3	0	0	0	
setting of tasks	comprehensible	f	20	8	0	0	0	incomprehensible
		m	11	3	0	0	0	
clarity	clear	f	13	10	3	0	0	confused
		m	8	6	0	0	0	
difficulty of tasks	easy	f	12	13	3	0	0	difficult
		m	5	6	3	0	0	
handling of apparatus	easy	f	17	9	0	0	2	difficult
		m	7	6	1	0	0	
gain of knowledge	excellent	f	13	13	2	0	0	very bad
		m	11	3	0	0	0	
do one’s own research	excellent	f	14	12	1	1	0	very bad
		m	11	2	0	1	0	

DISCUSSION AND IMPLICATIONS FOR TEACHER EDUCATION

From the results we conclude that the general pedagogic concept is adequate: participation of persons representing the target groups (students of different age, teachers of different types of school) is possible at all levels, i.e. construction of specific exhibits and experiments, designing experimental set-ups according to interest of specific groups. However, the opportunities available are not always taken up. It remains a problem that many teachers and their classes come as “tourists” not having prepared suitable “research questions” that could be solved in an open laboratory environment. In order to get closer to sustainable teaching and learning activities, it is necessary to actively encourage longer lasting cooperation with mutual responsibilities for students, teachers and tutors in the laboratory. In this way learning beyond school and incorporation of external facilities for learning could become more effective (Ramey-Gassert, 1997; Griffin, 1998; Paris, Yambor, & Packard, 1998; Zinicola & Devlin-Scherer, 2001).

It is evident, that “climate” is quite connected to environmental considerations of students. Students are aware of the topic (cf. Table 6), and they have some vague background knowledge already obtained at school or via the media (TV, print media). School and the media are the most important sources for actual or context specific knowledge. This seems to be a general phenomenon, since it is in accord with results obtained in different education systems (Aikenhead, 1988) as well as in previous school project work in the Rhein-Neckar-Region with respect to “biotechnology” (Schallies, Wellensiek, & Lembens, 2002).

The majority of students is interested in “climate” as a topic, in general male students more than female students. “Climate” definitely has something to do with the future, and is considered to be part of a general knowledge. However, quite a substantial number of students is not interested.

The topics “climate” and “carbon dioxide” fit in well with current curricula of all types of schools in the differentiated German system of schooling. Especially well so for grades 9 and 10 of secondary schools, or at the beginning of natural sciences classes grades 5 or 6. Although “Sachunterricht” (integrated approach for teaching natural phenomena) grades 3 or 4 of primary schools would fit in as well, teachers considered making use of the laboratory only in a very few cases.

Although students´ preferences for the topics are different, there is no difference noticeable when it comes to assess the experienced lab work. All aspects of the experimental part are highly judged, irrespective of students´ age, gender or type of school. Reasons for liking the experiments had much to do with "good teamwork in the group", external support by tutors and opportunities offered for students´ self-directed learning.

From participant observation it has become apparent that generally students do not have much previous experience with control of experimental design. They are used to lab work being an illustration of something that has been explained theoretically beforehand in teacher-centred learning activities. Also, they are not used to keeping variables constant or vary them in a systematic way. They have great difficulty in structuring records of experiments, or evaluate data quantitatively. However, social competencies are well developed, and also techniques for presentation of results of group work. All in all, we consider these findings to be in accord with a still classical orientation of science teaching in Germany, lab work being an "illustration, not a puzzle". It should be the other way round, lab work being a "puzzle, not a illustration" (Pickering, 1985). The traditional teaching concept in Germany is based on teacher-centred activities leading students through guided discussions and selected experimental activities to find the "right answer" to a carefully chosen and adjusted "problem" (Baumert, Lehmann, et.al., 1997). The ongoing debate about reform of the German education system in the wake of international studies like TIMSS and PISA has triggered many research and development projects aimed to improve students´ learning outcomes. This is a favourable circumstance for establishing external learning in a laboratory besides regular schooling.

From a point of view of a systemic approach to improve the existing education system, a unique visit to the laboratory is not sufficient. Therefore we are trying to foster long-term cooperations with schools. Only such cooperations will support a "full understanding of science" according to the definition outlined. The present development of the education system in Germany is favourable to such a long-term objective.

Tutors are essential in support of the self-directed student activities, because the interpretation of the laboratory findings will require theoretical knowledge, which is also necessary for interpretation of observations, or help interpret what students see. Otherwise activities will be unproductive, or as Liebig long ago pointed out: „An experiment not preceded by theory or a leading thought compares to research in natural sciences like a child's rattle to real music".

Training of tutors is essential, because from their own socialisation at school they are used to "instruction" being the reason for learning, having had practically no experience with self-directed learning during their own school career. Therefore seminars at the University of Education Heidelberg are offered to tutors, so that theory and practice have a chance to marry.

In December 2002 we had to close the laboratory in the museum at Mannheim because of lack of funding and the closure of the TA-Akademie. We have maintained and further developed the concept, and established the new laboratory "science-live" at our STS-Institute in June 2003. This makes possible the integration of students´ activities as tutors into the regular curriculum of the study of natural sciences at the University of Education Heidelberg. In this way we hope there are chances to develop students´ competencies for being a mentor of learning in theory and in practice.

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