PART 1

Hands-On Science and Informal Learning: Challenges and Potentials of Authentic Lab Activities

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Improving science literacy by various approaches

Physics education is under pressure. Science, technology and society are undergoing dramatic changes. The rapid increase of knowledge in a wide range of disciplines triggers scientific and technological developments that deeply affect our lives and transform our culture. Accordingly, a high proficiency in science and technology is considered a major factor for the economic prosperity of a country. Moreover, it is a prerequisite for developments that contribute to a sustainable future on a local as well as on a global scale. However, as international studies of educational achievements reveal, in many even highly developed industrial countries the level of scientific literacy is only poor. Young people are considered not enough prepared to respond to the challenges of a global and rapidly evolving knowledge society. The development of an adequate level of science literacy and new approaches to science education have become topics of broad national and international concern. As a consequence, various measures to increase the public awareness of science and programs to enhance the outcomes of science education have been launched in many places.
In Germany, programs to improve the quality of teaching and learning have been created that focus on mathematics and science in general [1], or on special science subjects as in the so-called context-programs such as 'chemistry in context' or 'physics in context' [2,3]. However, the ways of teaching science and the professional development of teachers respond only very reluctantly to the above challenges. Improving the quality of teaching and learning is a slow process, subject to many limiting constraints inherent in the system. In addition to these top-down efforts to promote quality development, a complementary movement, largely bottom-up, has emerged outside the formal education system. Driven by concerns about the declining interest of youngsters in science and technology and by the declining enrolments of students in these fields, many scientists at research sites and universities have taken up the initiative to create new ways of engaging young people in science and technology.
In order to counteract the imminent lack of scientists and engineers and to raise students' interest in science subjects numerous initiatives at universities, research institutes, and industry have established science labs for school students. For short, these out of school learning sites are called 'school-labs'. They offer lab-courses (mostly full-day or half-day) to complete classes or to individual students. School students have the opportunity to carry out specially designed experiments or experimental projects which are more or less closely related with the research carried out in the respective institutes. The labs offer an open, informal learning environment that focuses on activating, context based approaches and authentic learning experiences.

The present article provides evidence on the potential of (largely informal) learning in these learning sites outside the traditional school system. In contrast to initial criticisms, school-labs have a broad spectrum of beneficial effects. They have a high potential in changing the school students' and especially the girls' attitudes towards 'hard' science and technology. The apparent success of these projects might trigger off new developments that feed back on formal teaching of physics and enrich the professional development of physics teachers by components that have been neglected in the past.

Experiencing authentic science in school-labs: a success story

The school-lab initiatives are a bottom-up movement, driven to a large extent by highly engaged individuals in research institutes. The spectrum of initiatives ranges from small labs run by a single person to well equipped laboratories in large research institutes. In spite of wide individual differences among school-labs they share a common philosophy and pursue common goals. They intend to

- promote the interest of young people for science and technology
- provide a first hand experience of research or development
- support the development of adequate views of science and technology and their role for society
- provide opportunities to get in contact with scientists and to learn about professions related to science and technology.

The creativity of school-labs in engaging school students in authentic, interesting and challenging problems and the originality of the respective approaches and projects are impressive. Most labs have been created under the premise that carrying out experiments and practical lab work in a stimulating learning arrangement are essential factors for motivating young people. Moreover, depending on the subject area, school-labs may differ somewhat in their focus. Most labs concentrate on secondary I and secondary II students (age group 14-18). Chemistry labs tend to offer more courses for younger students. Physics and technology labs set an emphasis in trying to recruit possible candidates for these subject areas. As they focus on general methods and subjects related to the research institutes, their thematic link to school curricula is rather loose. Biology labs primarily tend to provide an adequate view of the methods of modern biology and biotechnology. As these subjects are also part of the biology syllabus, the curricular link of these initiatives is much closer.

Evidently, the lab courses meet the needs of the school system. Most labs are booked-out for months. Since the foundation of the first lab about a decade ago (cf. [4]), the school-lab movement took up an impressive momentum. At present, in Germany roughly 200 school-labs exist, that provide learning experiences for about 300 000 school students per year with. The numbers are still increasing. In terms of innovative learning approaches in largely bottom-up initiatives, the creation of the school-lab movement is a success story. For an overview and continuously updated information see the homepage of "LeLa-Lernort Labor" [5]. The LeLa project has been established at the Leibniz-Institute for Science Education (IPN) with funds from BMBF, the German ministry of Education and Research. As a center for consulting and quality development LeLa coordinates and evaluates these initiatives, carries out research on their impact, helps the initiatives in fund raising and contributes to their integration into the educational system.

Learning in the lab: challenges of creating a stimulating learning environment

School-labs intend to counteract an apparent paradox: Curiosity, originality and a lot of creativity characterize research and development in science and technology. At least, this is the opinion of active and successful practitioners in these areas. However, the public view of science and technology and the image of the corresponding school subjects is in a considerable contrast to that. Especially school physics is notorious for its bad image among students. The subject is often considered difficult, boring, detached from everyday experience, and socially not very attractive (for more details and further literature cf. [6]). When physics teaching starts at school, the rather high initial interest in that subject deteriorates rapidly. The decrease is much stronger for girls than for boys. Especially, the negative attitudes among girls towards school physics are highly problematic and have been diagnosed in pedagogic research since decades. However, in actual teaching, only little has changed despite of many proposals to circumvent the dilemma (cf. [7]). The girl's bad experience with school physics and their negative self-concept in that domain could be one of the reasons that only a minority of women select a career in engineering and similar professions.

Many science labs have been established under the guiding assumption that carrying out experiments and authentic lab work is a central factor to enhance interest in the subject and to stimulate knowledge acquisition. Thus, the "fun factor" in doing experiments and practical work plays a major role in the description of the pedagogic concept of the labs. Similar views are shared by physics teachers at school, who rate experiments and practical experience highly important for their teaching. However, as several meta-analyses on the role of lab work in schools have shown, motivation and successful learning in labs is not an automatism [8]. Creating stimulating learning environments that adapt to the various interests and cognitive abilities of students is far from trivial [9,10].

Studies on the use of experiments in school teaching show that strongly guided experiments prevail [11]. Cookbook-like procedures predominate and convey an insufficient, largely inductive, methodological image of how science works. Students are mainly required to manipulate apparatus and not ideas. They tend to confound following a recipe or working through a lab manual with the scientific method. Moreover, typical school science experiments in the introductory phase often are trivial, using strong didactic reductions. The relation to everyday life and the real world is frequently not recognizable. Creativity and challenges are missing, both requiring a certain degree of openness of the pedagogical approach. Additionally, the function of the respective experiment is often not made clear by the teachers. This applies to the role of the experiment in the teaching-learning process as well as to its role in the scientific inquiry process. In actual teaching, students do not have a real chance to get involved in the process of recognizing a problem, formulating a hypothesis and planning a task or an experiment to test their assumptions.

Thus, as evidence from actual teaching demonstrates, doing experiments offers no guarantee for motivation and successful learning unless it is integrated in a powerful teaching concept. What makes the school-lab supporters so sure that they are on a road to success? From the perspective of situated cognition and moderate constructivism, learning environments should conform to a set of certain criteria to enable meaningful learning processes [12]:

- They should be authentic, allowing the learner to deal with problems in realistic and not in artificially arranged situations.
- A problem should be presented and analyzed from multiple perspectives, using different approaches and methods of problem-solving.
- Approaching and solving a problem in different ways is a prerequisite for a flexible use of knowledge that allows a productive transfer of knowledge and methods to more distant problems.
- To have sufficient possibilities to explore and evaluate one's own ideas is a prerequisite for successful knowledge construction. Therefore, the learning

arrangement should leave sufficient space for the development of the students' own ideas and for following his or her own approaches.

- Knowledge construction takes place in and is facilitated by an appropriate social context that allows for cooperative and collaborative problem solving, e.g. in team work.

Although (at least in the initial stage) most of the labs have been created by subject matter experts and not by pedagogical experts, a closer look at their concepts reveals that they nicely fulfill a sufficient number of the above requirements that pedagogic theory has identified for successful interactive engagement of the learners and active knowledge construction.

Is it possible to motivate students by lab work?

As the above methods are highly demanding to the students as well as to the instructors, our evaluation focuses on the question: Is it possible to raise interest by confronting school students with authentic problems from research and to change the image of science in the long run? In the present article, we focus on describing the motivational effects of labs with a close affinity to physics.

Our main research question is to find out if the labs achieve their primary goal to increase students' interest in physics. Additionally, we try to identify factors in the design of the labs (like authenticity, openness, cognitive challenge and others), which are relevant to achieve that goal. In our theoretical framework, we have taken into account research on the role of practical work (see above) and on the design of learning environments which support interest [13]. According to the person-object theory, interest is a special relation of a person to an object [14]. Three main components of interest can be identified:

- Emotional component (characterised by positive feelings, fun)
- personal value (how important is the experience to me)
- epistemic dimension (reflects the desire to learn more about the field).

We consider these interest dimensions also relevant for learning and engaging in science. Therefore, we used them as the success criterion for the lab visit and designed a questionnaire accordingly to measure these main components of interest. We use the school students as "experts" for rating the labs, because the way the science lab is perceived by them is decisive for promoting their interest in science and technology. We assume that lab-specific and student-related factors and their interaction influence the potentials of science labs to increase interest. Therefore we choose an ATI-design (Aptitude-Treatment-Interaction). The relevant variables and their interactions are shown schematically in figure 1.

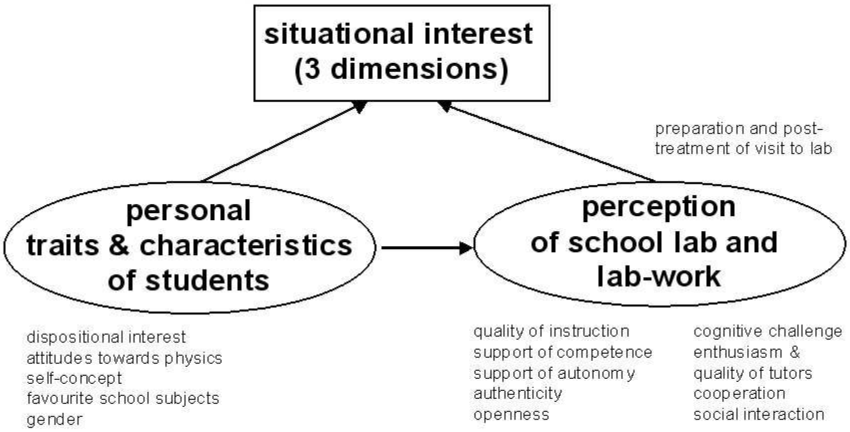

Figure 1: Design of the study

The data have been collected in a pilot study in 5 different school-labs. 330 Pupils from 15 classes (5 classes per lab) took part in this investigation [15]. In a replication study, we investigated more than 800 students in the same age group visiting 4 different labs of the German center for air and space research (DLR) [16]. In the pilot study, we administered two questionnaires, one immediately after the lab visit on site and a second one 10 to 12 weeks later. In the replication study, we used a three step pre-test, post-test and follow-up design. Both studies agree perfectly in their main findings. In the present discussion, only data from the first study will be referred.

School-labs in action: Positive long-term effects

On a descriptive level, the study shows that science labs are well accepted by the students. Nearly 75% would like to visit the school-lab again. This is not only because they miss regular class, but also because they have learned something about science and scientific research as we could conclude from their written comments. Especially, the contact with "real" scientists and the insight in their research institution is highly appreciated by the young visitors. Positive students' statements prevail. A collection of students' answers to the question "What did you learn in the lab?" three months after the lab visit gives a vivid impression of the level of involvement:

- I got an impression how science works. The aims of research in natural science have been made clear.
- I learned that research in physics has consequences for everyday life. The backgrounds of research processes were made transparent and one learns something about application of science.
- Even though I don't find physics very interesting, doing all the experimenting was fun.
- I learned that experiments are fun. I learned how research works, and that lab-work is arduous.

The laboratories work in very different ways. Whereas the student group with a high level of interest in physics develops an equally positive attitude for the different laboratories, large differences occur in the problem group of students with little interest. As an example, lab 2 demonstrates, that it is possible even for those students with limited initial interest in physics to develop a highly positive attitude (figure 2). It is plausible to attribute this positive effect to the specific approach of the lab. In comparison to the design of the other labs, it offers more supervised tasks, where students work in parallel on the same problem in a guided and stepwise manner. Obviously, weaker students favour this approach.

Students' perceptions of the lab-related variables have a differential impact on the components of interest. Multivariate regression shows that the emotional interest is influenced by "cognitive challenge", "comprehensibility" and "openness". The value-oriented interest is influenced by "cognitive challenge" and "authenticity". The epistemic interest (i.e. the desire to know more) interacts with "cognitive challenge". "Openness" is more important for students with high interest in science. In accordance with the finding of fig. 2, for students with low initial interest in science "comprehensibility" is highly important factor in raising motivation.

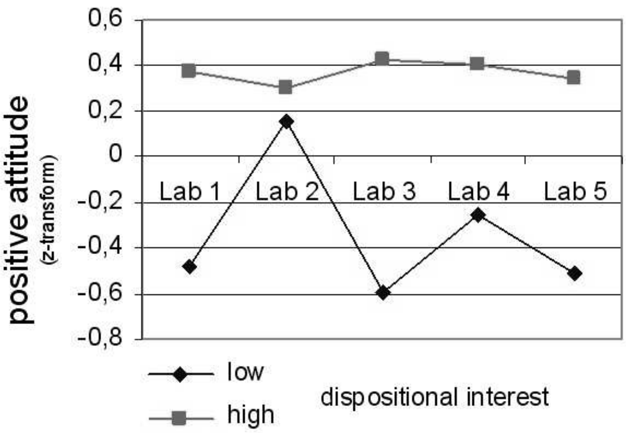

Figure 2: Attitude of students with different initial interest.

One of the main criticisms of the labs refers to their highly focused and temporally limited interaction. A single lab visit is only a short intervention. Some critics could not believe that a singular event could produce lasting effects and changes in the views of students. Our results provide clear evidence for positive and even long-term effects. The lab visit is rated important and the follow-up study shows that the personal significance of the visit is rated significantly higher after 10-12 weeks (figure 3). The effect can be seen for all five labs and for both groups of students with low and with high initial interest in physics. This surprisingly strong long-term increase shows that even a single visit to a science lab has a lasting impact. Obviously, the labs are effective – they have changed something in the heads of the students, and the change even continues over time.

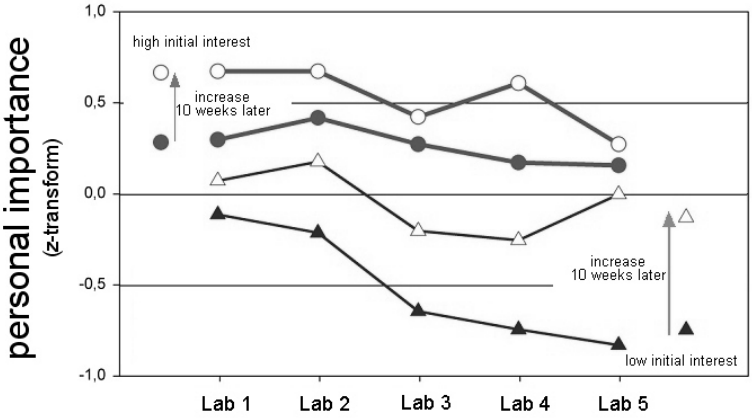

Figure 3: Development of the personal value of the lab visit for groups with low and high initial interest.

As a result, school-labs have not only a positive effect among groups of highly motivated students as some critics originally surmised. The labs are definitely in the position even to respond adequately to “problem groups”. For students with a limited initial interest and involvement in physics, the significance of the laboratory visit is mainly dependent on the demand level and on measures supporting the learners. Flexible concepts to react to heterogeneous target groups require an intelligent balance between the level of demanding (authenticity, challenge) and learner support (comprehensibility of the experiments and projects, scaffolding). Some labs could still improve on these measures. Also, more could be done with respect to materials supporting the visit. The results show that a visit to a lab is not well-prepared by the teachers of the visiting classes. Only in very few cases special schemes are established in order to prepare the visit and to maintain interest and support further activities after the visit, for instance by offering additional learning opportunities. Such measures could prove essential in enhancing the positive long term effect that shows up even after a single visit.

Practically no gender gap in school-labs

In addition to their positive long term effects, the science labs manage to equally address female and male students. Both girls and boys share similar positive attitudes regarding their lab-experience. Only minor gender differences were detected for the three components of interest (figure 4). The learning environment of the science labs and the possibility of conducting experiments in a stimulating atmosphere addresses both genders in a positive way. To some degree, this clear result came as a surprise, as most of the labs that took part in the survey do not address gender aspects explicitly. Meanwhile, in the replication study, the positive gender effects have been confirmed fully with a different set of physics and technology labs. The replication study gives a largely identical pattern for the three dimensions of interest. Therefore, we can consider the positive gender effects empirically well founded, that arise from interactive engagement in largely authentic science processes.

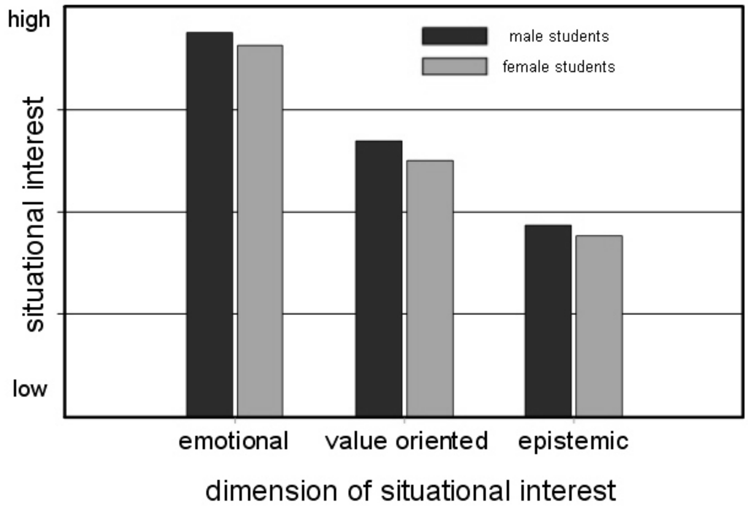

Figure 4: There are only minor gender effects in the ratings of boys and girls

The labs do something that regular teaching does not achieve. These findings from informal learning are in sharp contrast to physics teaching in regular classes. Physics as a school subject strongly polarizes between boys and girls. It is the least popular subject for girls. The present results from interacting "informally" with physics and technology in science labs provide clear hints what must be done to improve the "formal" learning environments in schools. Obviously, the broad authentic and problem-oriented approaches meet the girls' interests much better than the more narrowly focused systematic approaches of school physics. At the same time, this approach is also in line with the boy's interests. Both groups have the opportunity to appreciate the experiments and learn from their lab visit according to their widely differing own ways of approaching subjects from science and technology.

At least, such an interpretation can be concluded from an analysis of the students' statements, why they liked the visit to the lab. The statements of girls and boys show differences, which, to some extent, echo gender stereotypes. Male students like a more straightforward direct interaction with the experiments and the materials that reflects to some extent a trial-and-error method. In contrast to that, female students prefer a more reflective approach. Especially, they like to carry out experiments on their own and reflect about what they have learned from the experiments. Thus, in addition to the relevance of the subjects, the style of interacting with problems from physics and technology appears to play an equally important role to enhance the girls' motivation. Measures to improve the quality of school physics should include appropriate ways to learn from these positive experiences and provide better opportunities for both genders to interact with the methods of physics adequately, according to their individual styles and preferences.

Outlook: Challenges of innovation transfer from the school-lab movement

The results of our study show that, in spite of some initial scepticism, science labs achieve their main goal and enhance students' interest in science. Especially, they have a positive effect on girls' attitudes towards science and technology. The positive experiences with informal learning activities could be used more systematically to enrich the formal education system by providing authentic and attractive ways of engaging young people in learning and by doing up-to-date science in interesting and challenging projects. Moreover, school-labs could play a leading role in supporting young talents and creative minds that our society desperately needs to promote innovations.

It has been mentioned that the school-lab initiatives are a bottom-up movement, driven to a large extent by highly engaged individuals. This makes up their appeal and potential. However, it also makes up an inherent weak point, as the initiatives largely act independently. Their public visibility is still poor, and a broad support is needed to develop a permanent impact on educational policy. Additionally, the question of funding these initiatives requires collective efforts and broad alliances, such as public-private partnerships.

At present, a coherent approach integrating formal and informal learning is still lacking. The function of informal learning in these extra-curricular learning sites has to be clarified and made explicit. Is it complementary or supplementary to learning in the formal education system. The question, how teachers can be involved needs to be addressed more actively in the future. Science labs could play a more prominent role in the professional development of teachers by engaging them in different phases of their professional career. Innovation transfer from the labs to traditional science education could be enhanced considerably. Additionally, science labs could take up additional functions in the fields of vocational education and lifelong learning. It is a challenge of ongoing activities that these informal learning sites will become a reliable pillar within the traditional education system.

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