Supporting practical science learning for all students – A German cross-country initiative in non-formal chemistry education

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Non-formal laboratory learning environments for school students, in German called “Schülerlabor”, were founded recently in many German universities originally for motivational purposes. The intention was to overcome a shortage in young people embarking into academic careers in science and engineering. Thus, Schülerlabor settings in the beginning were mainly focusing on older and higher achieving students. This chapter reports a different approach. The project “Chemistry, Environment, Sustainability: Non-formal Learning Environments for All Students” focuses thoroughly on science learning for all students via a Schülerlabor environment. This article presents a special model for differentiated teaching and learning in Schülerlabor environments, which was developed in the course of the project. The model takes into account students’ diversity in their personal interests, cognitive achievement, problem-solving skills, and linguistic capabilities. The project also focuses on developing creative approaches to chemistry experiments for motivating especially those students who are originally less skillful and less motivated in learning science.

Introduction

In 2012, the OECD described the growing importance of informal and non-formal education to support formal learning in schools. Informal learning was defined as out-of-school learning without a given structure and curriculum. Examples for informal learning include individual visits to museums, zoos, or science exhibits, but also viewing science-related programs on TV and videos, or reading articles and books in printed or digital form. Also non-formal learning occurs outside traditional school environments. However, non-formal learning tends to have a specific structure and is often connected to various types of prescribed programs or curricula (Coll, Gilbert, Pilot, & Streller, 2012; Stocklmeyer, Rennie, & Gilbert, 2010). Coll et al. (2012) pointed out that the terms informal and non-formal learning, although officially defined and widely used, are often incoherently applied.

Reflecting two examples from Ireland and Germany Garner, Hayes, and Eilks (2014) recently discussed the potential which non-formal educational initiatives have with respect to curriculum development and innovation in science education. They pointed out that the greater freedom and flexibility available in non-formal education provides rich opportunities for learning, but also for developing and testing of new teaching and learning scenarios, e.g., new experiments and media. They also referred to the early implementation of current topics into science teaching and learning.
The Schülerlabor as a place for non-formal learning and innovation

In Germany, a special type of non-formal learning laboratory environments emerged in recent years to promote primary and secondary science education, the so-called Schülerlabor (Haupt et al., 2013). The name Schülerlabor (SL) can be translated as student laboratory. In Schülerlabor, the word ‘Schüler’ in German refers to school students exclusively, not to university students. ‘Labor’ is the German term for laboratory (Garner et al., 2014). Today, more than 300 SLs exist all over Germany. Most of them are connected to universities, but also to large research institutes, or industry plants (Hempelmann, 2014).

SLs were founded in universities originally to motivate school students to later embark into academic careers in science and engineering (Bloemen, Heyse, Porath, & Schlömer, 2012). For this purpose, most SLs in the beginning were focusing on older and higher achieving students. Over time, the idea of operating SLs developed into a broad nation-wide movement. Its intentions changed to support science learning on a more general level by offering students of all schooling levels out-of-school learning experiences and provide them chances to do practical work beyond the limited possibilities most schools have to offer, limited by a lack of equipment, time, or the overall quality in the school science resources. The rationale behind the SLs today is to promote science learning at all levels and to improve students’ engagement in science and engineering studies in general (Haupt et al., 2013).

Typically, SL-visits are half- or full-day excursions of whole classes to well-equipped university laboratories, where practical lessons take place. SL-visits in most cases are compulsory learning events for all students, since the whole class does the excursion together with the teacher as an official school event. Activities in the SL generally follow a prescribed structure and the visits are not always connected to the school curriculum. In many universities SLs are also used as part of pre-service teacher education in asking student teachers to supervise school classes in the SL as part of their university teacher education program (Hempelmann, 2014; Haupt et al., 2013).

Research on the effects of the SLs is still limited. However, initial studies indicate that SL-visits can have potential for achieving positive short- and medium-term effects with regard to levels of situational interest and motivation (Guderian & Priemer, 2008). Itzek-Greulich et al. (2014) demonstrated that SLs can also lead to improvements in cognitive achievement. Both Itzek-Greulich et al. (2014) and Zehren, Neber, and Hempelmann (2013) have concluded that repeated visits to the SL, especially when adapted to formal learning in school, can also lead to long-term effects in terms of motivation and achievement.

Garner, Siol, and Eilks (2015) described already a SL-project which clearly was focusing the implementation of current topics from chemistry and chemical technology into science education under consideration of contexts from and issues of sustainable development. Their project documented promising indications of a rise in student motivation. They also generated useful contributions to curriculum innovation and ideas for continuous professional development for teachers in the field of education for sustainability. Students and teachers learned about current
developments in sustainable chemistry, e.g., ideas of green chemistry. Teachers had also a chance to learn about innovative pedagogies and experiments. They were able to get new ideas about teaching and new issues, and in the same time they experienced how their students react to them. SLs also offer situations where teachers can support their students individually, thereby developing personal views of themselves and their students. Teachers improved both their content knowledge and pedagogical content knowledge, and learned how new experiments and experimental techniques can be effectively carried out in educational settings.

Chemistry learning and education for sustainability in the Schülerlabor for all students

A cross-country initiative of non-formal student laboratories for all students

Non-formal education in the SL aims to motivate students to continue their studies in science and engineering (Haupt et al., 2013). Therefore, in recent years many corresponding learning environments have been established at German universities, which originally targeted mainly upper secondary science students and higher-achievers. However, a focus on this group might overlook important opportunities of SLs to extend science education for all students, e.g., in the field of education for sustainability (Affeldt, Weitz, Siol, Markic, & Eilks, 2015).

Environmental attitudes and acceptance of sustainability thinking tend to be quite developed among more mature, higher-achieving students, especially those with advanced educational backgrounds (e.g., based on a high socio-economic status and academic background of their parents). The opposite is the case for many students with less-advanced educational biographies (Michelsen, Grunenberg, & Rode, 2012). These learners often come from an environment characterized by a lower socio-economic status, a migration background of either the students or their parents, and sometimes are connected to lower linguistic skills. Often lower educational achievement in the sciences and less well-developed attitudes towards environmental stewardship, including knowledge and skills in questions of sustainability, have been found in this group of students (Michelsen et al., 2012).

Education for sustainability among students with less advanced educational biographies presents new challenges, since these students also have problems with general school achievement in many cases (Michelsen et al., 2012). To address these challenges, the project “Chemistry, Environment, Sustainability: Non-formal Learning Environments for all Students” has begun in which SLs offer all students, either with a more advanced educational background or with a disadvantaged educational biography, the chance of developing their knowledge and skills concerning sustainability issues in chemistry-related contexts (Affeldt et al., 2015).

In the project by Affeldt et al. (2015) teaching and learning environments for lower secondary school science and chemistry classes as well as learning groups from other non-formal education providers, such as tutoring clubs, are developed. The project uses university laboratory visits as the central pivot points. It employs the cooperation
of four SLs located at four different German universities across the country, namely the Universities of Bremen, Erlangen-Nuremberg, of the Saarland at Saarbrücken, and the University of Education in Karlsruhe.

All the project partners maintain well-established SLs and drive in-service chemistry teacher education centers for dissemination of the project outcomes. The partner at the Institute for Science Education of the University of Bremen is developing and piloting the learning environments. These are then transferred to and adapted by all of the other partners. The aim is to have each partner generate a minimum of 1500 students who have visited the different learning environments from each of the four SLs within a period of three years.

With regard to the organization of the non-formal SL visit, the learning experience is meant to be prepared in school by teachers before their classes visit the university laboratory environment. All of the laboratory instructions and supplementary materials, e.g. information for how to behave at the laboratory, are provided to the teacher by the SL staff before the visit. A manual explaining the background and the range of possibilities for the SL-visit is also given to the teacher. It contains copies of the laboratory instructions and suggestions for further reading. This enables the teacher to acquire an overview of the topic and to prepare the students for the activities to be performed. The SL-visits take generally three hours. The target groups are secondary school science and chemistry classes in grades 5–10 (age range 10–16). If the teachers want to extend the time, additional activities are provided. All topics for the different SL-modules have been chosen to meet the essential competencies and contents addressed by the aspect of sustainability (Table 1).

**Table 1. Overview of the differentiated non-formal learning environments**

<table>
<thead>
<tr>
<th>Grade</th>
<th>Module</th>
<th>Aspect of Sustainability</th>
</tr>
</thead>
<tbody>
<tr>
<td>5/6</td>
<td>Discovering old crops for chemical and pharmaceutical industries</td>
<td>Stewardship of resources and the use of renewable raw materials</td>
</tr>
<tr>
<td>5/6</td>
<td>Exploring and improving water quality</td>
<td>Purification and efficient use of limited resources</td>
</tr>
<tr>
<td>7/8</td>
<td>Protecting and preserving metallic objects</td>
<td>The reduced need to continually use of natural resources</td>
</tr>
<tr>
<td>7/8</td>
<td>The contribution of chemistry to sustainable mobility</td>
<td>Renewable energy sources to protect resources and limit climate change; innovative materials for lightweight engineering</td>
</tr>
<tr>
<td>9/10</td>
<td>Energy storage for energy change</td>
<td>Sustainable energy supply, new technologies for energy storage, realizing greater energy efficiency</td>
</tr>
<tr>
<td>9/10</td>
<td>Bioplastics for a more sustainable future</td>
<td>The properties, synthesis, application, and recycling of different bioplastics</td>
</tr>
</tbody>
</table>

Each of the learning environments offers a set of roughly 20 experiments of which teachers can select some. Such intense learning experience in school is generally not possible because of limitations in time for preparation, equipment, and infrastructure. All chemistry and sustainability learning aspects have been embedded into contexts taken from everyday life issues, the environment, or technology. The focal points of
the various modules cover the properties of substances, electrochemistry, organic chemistry, and sustainable technologies. Each module also includes a specific aspect of sustainability. The topics include water quality and water treatment, protecting and preserving objects, modern technologies in the context of sustainable mobility, and the sustainable synthesis of modern materials. Within the SL environments learning for sustainability is related to chemistry-specific contents and contexts, so that students can understand and participate in corresponding socio-scientific discussions. This also should allow them to make educated choices regarding whether professions in science and technology make sense for their future careers.

A model for differentiated learning in the Schülerlabor

One of the central pedagogical innovations in the present project is operating a detailed model for differentiation. The model takes into account students’ diversity in their personal interests, cognitive achievements, problem-solving skills, and linguistic capabilities (Figure 1).

![Figure 1. Model for differentiated learning environments in SLs (Affeldt et al., 2015)](image)

The model provides guidance to structure highly differentiating teaching and learning environments, which are developed and tested for use in the SL environments within the project. Each of the learning environments consists of three to five sub-topics that are composed of each four to six individual experiments. The various experiments in any of the sub-themes differ in their complexity and depth of cognitive demand. This
allows aligning the learning environment with students’ prior-knowledge, cognitive skills, and problem-solving capabilities.

The aim of differentiated instruction is to enable all students to solve each of the tasks on their own. Thus, all of the experimental tasks are developed with regard to a student-centered, inquiry-based pedagogy. Students work in groups of two or three in a cooperative learning process. Experimental instructions are given for doing the experiments in an open to guided inquiry approach (Blanchard et al., 2010). “Help Cards” and “Solution Cards” (that offer a help on different levels) are implemented to allow lower-achieving students to master at least a structured inquiry learning process.

Different tools are available to support students at different performance levels. “Help Cards” are provided covering the phenomenological-descriptive, the verbal-explanatory, the sub-microscopic, and formal-representational levels. The cards focus on the content and process of scientific inquiry. As a language helping tool, terms and definitions are provided including the definite articles for German nouns in both the singular and plural forms. Every exercise aims on repeating and building upon knowledge, but to also improve the students’ language skills. Many experimental descriptions are supported by sketches and sequences of pictures. The students have also access to “Help Cards” with respect to linguistic issues. The students are free to decide whether to use the cards and on what kind of level they feel need for them. Furthermore, different tools for students with a general lack of linguistic capabilities have been implemented, e.g. lists of vocabulary (with articles and plural forms) or words for helping to write up the operation, observation and discussion of an experiment (e.g., beginning of the sentence, connecting parts of the sentences, drawings as explanation, and clozes).

Another innovation is that the project thoroughly focuses creative approaches towards experimental instructions, e.g., comics, entries in Internet forums, blogs, Facebook, Twitter, as well as on- and off-line news media (Figure 2). These tools aim on raising students’ motivation and help lower barriers towards the experimental tasks, which are often caused by linguistic deficits among many of the target group students.

One example in practice

The SL learning environment Exploring and Improving the Quality of Water targets grade 5–6 students (age range 11–13) in lower secondary science education. The curriculum-relevant contents are properties of matter, different methods for separation of matter, as well as water quality and waste water treatment. The learning environment shall promote a critical view on water as an essential everyday substance and the importance of water quality for our life and the environment. Knowledge about how water affects life and environment is needed to understand the necessity to protect the quality of water and to sensitize for a careful and economic use of water. Changes in learner’s attitudes towards the quality of water shall concern the limited availability of this natural resource.
Figure 2. Two different creative approaches towards experimental instructions (comic on the left and entry in Instagram on the right)

The learning environment includes an offer of seventeen experiments divided into three sub-topics (Table 2). The topics are selected based on their importance for sustainability and relevance to the school curriculum. The experiments in the sub-topics differ in the degree of cognitive demand and complexity (Table 3).

Table 2. Sub-topics of ‘Exploring and Improving the Quality of Water’

<table>
<thead>
<tr>
<th>Subtopic</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>The properties of water</td>
</tr>
<tr>
<td>2</td>
<td>Exploring water as a natural resource</td>
</tr>
<tr>
<td>3</td>
<td>Different separation methods</td>
</tr>
</tbody>
</table>

In sub-topic 1 the learners consider the properties of water in five different experiments. The contents are connected with contexts and issues from life and environment. The learners explore the surface tension of water, the limits of solubility, the solubility of solids in water, the solubility of gases in water and the different chemical states (solid, liquid and gaseous) of water in the different experiments. Each experiment usually is handled in 15 to 25 min.

Sub-topic 2 focuses on exploring water as a natural resource. In the experiments the learners inquire different mixtures including solid and liquid substances solved in water. The students evaporate wastewater and water with salt to discover and inquire the residues with the microscope. Learners are asked to link the findings from sub-topic 1 and 2 with the quality and the use of water in their everyday life.
In sub-topic 3 various opportunities for the separation of mixtures, e.g., water and sand, water and oil, or wood, iron and water are given. The experiments show learners how methods for the separation of matter can be used to improve the quality of water. The use of activated carbon, sedimentation, decantation, different filters and distillation are compared and their potential for the treatment of waste water shall be discussed. The experiments vary in their complexity and their depth of cognitive as well as motoric skills from each experiment 1 to 7. In the most complex experiment, no. 7 of sub-topic 3, the learners are requested to clean a mixture of water with oil, sand, salt, iron filings, wood shavings and ink by using all the different methods for separation of matter.

Table 3. Experiments in the different sub-topics

<table>
<thead>
<tr>
<th>Subtopic</th>
<th>Experiment</th>
<th>Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1 Cleaning up after the party</td>
<td>Surface tension</td>
</tr>
<tr>
<td></td>
<td>2 The over-salted water</td>
<td>Limits of solubility</td>
</tr>
<tr>
<td></td>
<td>3 Which solids dissolve in water</td>
<td>Solubility of solids</td>
</tr>
<tr>
<td></td>
<td>4 Gases in water</td>
<td>Solubility of gases</td>
</tr>
<tr>
<td></td>
<td>5 Just water</td>
<td>Aggregate states</td>
</tr>
<tr>
<td></td>
<td>1 Exploring of mixtures</td>
<td>Solubility of different substances in water</td>
</tr>
<tr>
<td></td>
<td>2 The magic water</td>
<td>Comparing water and lime water</td>
</tr>
<tr>
<td></td>
<td>3 Hard and soft water</td>
<td>Lime in Water</td>
</tr>
<tr>
<td></td>
<td>4 Evaporation of water samples</td>
<td>Evaporation</td>
</tr>
<tr>
<td></td>
<td>5 Tiny substances very large</td>
<td>Microscope for microstructures</td>
</tr>
<tr>
<td>2</td>
<td>1 Magnetic separation</td>
<td>Magnetism</td>
</tr>
<tr>
<td></td>
<td>2 The magic powder</td>
<td>Purification by activated carbon</td>
</tr>
<tr>
<td></td>
<td>3 Sedimentation</td>
<td>Sedimentation</td>
</tr>
<tr>
<td></td>
<td>4 Decantation</td>
<td>Decantation</td>
</tr>
<tr>
<td></td>
<td>5 Various filters</td>
<td>Filtration</td>
</tr>
<tr>
<td></td>
<td>6 Distillation of salted water</td>
<td>Distillation</td>
</tr>
<tr>
<td></td>
<td>7 The individual treatment plant</td>
<td>Different separation methods</td>
</tr>
</tbody>
</table>

The differentiated instructions of this non-formal learning environment contain graduated learning aids which are illustrated in the instructions by different symbols. The aids are available to support students at different performance levels and allow all students, both lower- and higher-achievers, to participate in the inquiry process. Creative approaches using towards the experimental instructions are selected according to the age range of the students, their social environments and everyday lives. Thus, mainly comic illustrations were used in the experimental instructions of this learning environment.

Development and evaluation

Method and sample
The development of the learning environments follows a cyclical process of design, testing, evaluation and optimization. Questionnaires for learners are used in each implementation phase. The student questionnaire focuses on the learner’s perception of the topics, the instructional materials, the selected pedagogies, and the language-sensitive design. It includes a total of 10 items with four-point Likert scales and two open-ended questions. The data interpretation is triangulated by relating the answers from the questionnaires with teacher observations and the observation protocols provided by the SL staff.

Learning environments for the six different topics are currently implemented in all the four SLs at the different partner universities. So far, a total of 1091 students have visited the differentiated, non-formal learning environments in one of the four student laboratories. 748 of these students visited a non-formal learning environment in the SL in Bremen. Since autumn last year 11 learning groups with a total of 244 students visited the learning environment Exploring and Improving the Quality of Water. Most of the students came from urban comprehensive schools with a particularly high rate of students having a migration background.

Findings and discussion

The findings discussed here refer to those students having visited the non-formal learning environment Exploring and Improving the Quality of Water in the SL in Bremen since October 2015 (N=244). Almost all students indicated that the experimental instructions encourage learning about chemistry. More than 90% of the participants agreed strongly or mainly to a statement corresponding to this (Figure 3).

Connecting the experimental instructions with comics is deemed to be motivating by a large part of the students. A statement according to this met high level of agreement (about 40%), with another group of about 40% agreeing mainly. Additionally, almost the half of the students (50%) indicated strongly and about 40% indicated mainly that it was easy to understand the information in the comics. The vast majority of the students responded with at least strongly and mainly agreement that the learning “Help Cards” for the experimental instructions were helpful (about 80%). Only a small percentage of the students fully or mainly agreed to the statement that they did not understand the words in the experimental instructions (about 25%) and that the tasks were difficult (about 20%).

The exact opposite is shown in the statement concerning the personal interest of the students. Almost all students (over 90%) are in fully or mainly agreement with the statement that the tasks during the SL were interesting. The students’ answers also indicated that the visit of the SL had positive influence on their opinion about science and changed attitudes towards chemistry in particular. Roughly 80% strongly or mainly agreed that they experienced how important chemistry is for their personal life. More than 90% of the students met high levels of agreement with the statement that they just know (after the visit of the non-formal learning environment) that chemistry is important for sustainability issues. Additionally, over half of the students indicated that the visit of the SL will have an influence on their behavior. More than
50% fully and roughly 30% mainly agreed that they think that they will give more consideration to the environment. Answers to the open-ended questions and teacher’s feedback support the indications of very positive overall feedback. Both students and teachers, which shared their feedback orally in conversations with the staff of the student laboratory, thought that the visit to the SL contributed to raising students’ motivation towards science learning, as well as increasing the overall learning effects with respect to social skills. The teachers especially valued the creative design of the instructions, particularly with regard to the everyday lives of their students. These initial results indicate that such learning environments in their differentiated form, including the various combinations of innovative pedagogical tools, have potential to promote students’ interest in science and increase motivation. The findings parallel experiences from other previously implemented learning environments focusing on chemistry learning in sustainability contexts (Garner et al., 2015; Salmi, 2003).

![Figure 3. Results of the questionnaire-based study with a total of 10 items](image)

**Figure 3. Results of the questionnaire-based study with a total of 10 items**

**Conclusion**

Mischnick and Faustmann (2014) stated that if SL learning environments are well-adapted, even lower-achieving students can become highly motivated and profit from the practical work offered within the SLs. In the SL environments described here, the students were exposed to contextualized learning environments with a set of pedagogical innovations. These innovations have the goal of opening science learning to all learners with the support of multi-differentiated learning environments which take the learners’ personal interests, varying cognitive capabilities, and heterogeneous linguistic skills into account. This project wishes to promote student motivation and science learning, but also to provide improved learning opportunities on topics from
chemistry relevant to education for sustainability to learners from both educationally advantaged and disadvantaged backgrounds (Affeldt et al., 2015).

The overall student and teacher feedback was very positive. The different topics presented by the learning environments, as well as the pedagogies applied in them, were seen as interesting, relevant, and feasible by the participants. Connecting science learning to authentic issues within the sustainability debate proved motivating and meaningful to the learners. Feedback from students and teachers provided initial indications that approaching science learning through sustainability-relevant topics using the new model of differentiation is a promising approach. The given structure of the SL environments can help make learning experiences more manifest and to allow a larger number of students to find their own approach to science learning.

The case study described in this paper was also focusing on changes in learners’ attitudes towards science learning, sustainability, and the personal as well as societal dimension of chemistry. The findings indicated that the students started recognizing the importance of chemistry for their personal life and for sustainability issues. The study indicates that visits of sustainability focusing SL environments can also have a positive influence on students’ behavior in their every-day life, although this influence should not be overestimated. Further research within the given project will now focus differences concerning students’ privileged and disadvantaged educational backgrounds. In doing so, a special focus will be put on differences between students with varying educational biographies, achievement levels, and attitudes towards science education and on the various creative approaches used in the experimental instructions.

Acknowledgments

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References


