

Article

The Potential of Non-Formal Laboratory Environments for Innovating the Chemistry Curriculum and Promoting Secondary School Level Students Education for Sustainability

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Academic Editor: Ian Thomas

Received: 1 December 2014 / Accepted: 3 February 2015 / Published: 10 February 2015

Abstract: Developing skills and attitudes among students in terms of Education for Sustainable Development (ESD) requires that educators address issues of sustainability in both formal and non-formal education. However, up to now, ESD seems to have been insufficiently implemented in secondary science education in many countries in general, and in high school chemistry learning in particular. A lack of suitable experiments, coupled with missing teaching and learning materials and insufficient teacher professional development have been identified as the reasons for this gap. This paper describes a project of innovation and research in the field of ESD for secondary school chemistry education. Within the project, both half- and full-day learning environments have been developed for non-formal, laboratory-based learning of secondary level students at the university. The research-based development focuses on teaching-learning modules which link formal and non-formal learning. The pedagogy employed is both learner-centered and inquiry-based. All the modules focus on sustainability issues in chemistry-related contexts. Data was collected by questionnaires from teachers and students both prior to and after the visit of the non-formal learning environment. Likert-items were analyzed statistically and the evaluation of the open-ended questions was done by Qualitative Content Analysis. An overview of the project,

a case from the non-formal laboratory setting, and findings from accompanying research and evaluation are discussed in this paper. Potential impacts on teacher professional development and curriculum innovation are also outlined.

Keywords: chemistry education; education for sustainable development; non-formal education; curriculum innovation; biodiesel

1. Introduction

As one result of the Club of Rome's report "*The limits of growth*" [1], the idea of sustainable development was developed in the 1970s and 80s to be "*development that meets the needs of the present without compromising the ability of future generations to meet their own needs.*" [2] (p. 11). In 1992, the United Nations defined sustainability and sustainable development as normative, guiding principles of the international community, the world economy, global civil society, and politics in its Agenda 21 [3]. According to the Agenda 21, sustainable development encompasses a balanced view of ecological, economic and socio-cultural sustainability.

Already in Agenda 21, education was identified as a key domain for realizing the concept of sustainable development [3]. The idea of Education for Sustainable Development (ESD) was raised. The central focus of ESD was the suggestion to prepare younger generations to become responsible citizens by becoming able to participate in a democratic society in order to shape society for a sustainable future. The students should learn to take responsibility for both themselves and future generations and to act accordingly, based on the idea of sustainable development [4].

Without a doubt, chemistry and the chemical industry in the past have been responsible for many non-sustainable developments that contributed to strong resources consumption and different environmental problems [5]. However, today, the aim of any modern production process in chemistry is to reduce emissions, waste, and raw materials or energy usage. In times of increasing scarcity of many raw material resources for chemical production, available feedstock needs to be used most efficiently. Chemical societies worldwide have developed frameworks to fulfill this responsibility [6]. *Green* or *Sustainable Chemistry* became a guiding framework for contemporary chemistry research, development, and industrial production [7]. "*Green chemistry is the utilization of a set of principles that reduces or eliminates the use or generation of hazardous substances in design, manufacture and application of chemical products*" [8] (p. 11). Anastas and Warner identified twelve guiding principles for chemical processes, which are intended to implement sustainability into chemistry [8]. Such principles enable sustainable production processes if industry respects them.

Accordingly, innovations in chemistry education have a special responsibility to also address the corresponding issues in teaching under consideration of modern developments in the sense of sustainable and green chemistry. Recently, Burmeister, Rauch and Eilks [5] reviewed potential practices and initiatives as how to integrate chemistry education with ESD. Approaches range from adopting Green Chemistry principles to practical work in chemistry education, via context-driven and socio-scientific issues-based contention with ESD topics in the chemistry classroom, towards chemistry's contribution to sustainability-focused institutional development. In Burmeister *et al.*, it is suggested as being

insufficient to merely integrate sustainability-related content into the chemistry curriculum. On a more general level, interdisciplinary and holistic approaches have been suggested to promote ESD, such as socio-scientific issues-based teaching or institutional development [9]. So do Burmeister *et al.* for chemistry education and also suggest corresponding skills development measures [5].

In practice, there seems to be a general willingness to incorporate ESD into formal science education [10]. There is also an acknowledgement of the growing importance of sustainability issues in chemistry research, production, and society [6], as educational initiatives become increasingly available [4]. Nevertheless, corresponding lessons are yet hardly implemented in most secondary school chemistry classes [5]. A lack of suitable experiments, insufficient teaching, a lack of learning materials feasible for classroom implementation, and the lack in corresponding teacher professional development opportunities were all identified as the reasons for this remaining gap [5].

This paper highlights the need to integrate aspects of sustainability in formal and non-formal chemistry learning environments at the secondary school level. A project is presented here which promotes learning about sustainability in chemistry classes. Within the project both new teaching, learning materials and experiments on sustainability in chemistry-related contexts have been developed and integrated into chemistry learning via a non-formal learning environment for high school students. The non-formal learning environments are also used to introduce modern topics from the sustainability debate to secondary school teachers. They also bring them into contact with corresponding curriculum materials and pedagogies. During visits to the non-formal learning environment, both the students and their teachers experience new experiments, materials and pedagogies. An overview of the project's outline and an example from the non-formal laboratory learning environment are given. Findings from accompanying research and evaluation are discussed, as well as descriptors for teacher professional development and curriculum innovations are outlined.

2. Theoretical Background

2.1. Socio-Scientific Issues-Based Science Education as a Way to Promote ESD

Secondary science education is often criticized, because students perceive it as irrelevant to their lives, especially in the domains of chemistry and physics. One reason which has been suggested is a lack of suitable contexts for science learning in many countries, which effectively respect the individual relevance and societal dimension of science education [11]. One answer to this dilemma might be a more thorough societal orientation of chemistry education [12], which should include a clearer focus on general educational skill development instead of the rote memorization of science facts and theories [13].

Sadler as well as Marks and Eilks argue that socio-scientific issues need to be addressed so that they become the drivers of skill-oriented chemistry education [14,15]. Sadler places special emphasis on current environmental issues that are often mentioned in public and political debates [14]. Eilks and Hofstein connect this view clearly with both the question of the relevance of science education and ESD [16]. ESD-related socio-scientific issues might help to make chemistry learning more motivating, meaningful and skill-building. ESD is essential to enable future generations to handle current local and global sustainability issues. Therefore chemistry education needs to contribute to this area [5]. Pupils need to learn that they bear the responsibility for themselves and for future generations [4].

To promote ESD, UNESCO proclaimed the World Decade of Education for Sustainable Development (DESD) for the years 2005–2014. The aim was to enable pupils to act in a sustainable fashion and to shape their future sustainably via all domains and levels of education [17]. Problem-based learning processes as well as a skills-oriented teaching paradigm are needed in order to promote ESD actively [18]. At the end of DESD in 2014 UNESCO has implemented a global action program (GAP) on ESD to build on achievements and to provide further development [19]. Underlying theories to support this point of view are Activity Theory, a Bildung-oriented understanding of chemistry education, or the idea of a development of shaping competencies [4,13,20]. Such skills will enable students to effectively participate in society and deal with sustainable challenges both today and in the future [21]. These skills are essential for enabling students to assess new chemistry-based products and technologies and to respond appropriately [22].

The DESD led to numerous projects which attempted to integrate ESD into chemistry education. Accompanying research showed that aspects of green chemistry [23] and ESD-related socio-scientific issues are well suited to integrate ESD into chemistry education. Examples for corresponding socio-scientific issues center around learning about fats/esters or alcohols, based on the discussion about the use of biodiesel and ethanol as fuels, respectively [24,25], comparing bio-plastics and conventional polymers [26], or learning about risks of components used in everyday life cosmetic products [27]. Studies show that ESD leads to an improved understanding of the importance of science in daily life [26] and students also become more open to learning chemistry [28].

2.2. Effects of Non-Formal Learning Experiences

Hopkins and McKeown state that formal education alone is unable to fully carry out the challenges of ESD [9]. Out-of-school learning environments need to be incorporated. UNECA reported that ESD works very well when formal and out-of-school learning work hand-in-hand [29]. Regarding out-of-school learning environments, a distinction has to be made between *informal* and *non-formal* learning environments [30]. The main differences are whether learning has a specific structure and whether it is connected to any kind of a formal syllabus or curriculum. Formal learning is always organized, structured, focused around learning objectives, and located in a formal institution such as the school. Informal learning is voluntary, never organized. Visiting a museum on the weekend is an example for informal learning. Non-formal learning settings lie in between informal and formal learning. Non-formal learning is less organized than formal learning, however, it also has a given structure, learning objectives, and can be compulsory [31].

Holbrook proposes enriching formal education by field trips to ensure ESD in formal learning situations [32]. Museums and science centers are proposed as potential partners [33]. Field trips, excursions, and out-of-school settings have shown potential for supporting science learning at different levels [34]. Although not all of the following effects are in the focus of this study, a short overview about the broad effects of combining formal and non-formal learning shall be given: Motivation, a positive perception of learning, support of career choices by identifying personal interests, and continuous professional development of the accompanying teachers are all listed as benefits. Research has shown that field trips may lead to increased motivation and interest, as well as an improved attitude towards the topic (e.g., [35,36]). Salmi disclosed that field trips can change situational motivation into intrinsic

motivation and can also influence academic career choices [37]. Field trips may also lead to positive cognitive learning outcomes [38]. However, the long-term effects of field trips are only poorly understood. A few months after field trips, strong but only nonspecific memories of the experiences were generally found [39]. In terms of ESD, however, it was shown that field trips can cause a longer lasting change in attitudes and environmental awareness [40].

Wolins, Jensen and Ulzheimer have pointed out that linking out-of-school learning with the school curriculum, including multiple visits, enhance long-term learning effects [41]. The novelty of a learning environment is another factor that influences the impact of a field trip. Very unfamiliar learning environments can reduce student learning. Learning environments which do not differ from formal learning may have the same effect [38]. It has been suggested that making the students familiar with the out-of-school learning environment prior to the trip can be a help. However, the effectiveness of field trips is influenced by many different factors which were summarized in a review by DeWitt and Storksdiel [42]. The complicated interconnectedness of these factors is, however, still not fully understood. Nevertheless, linking out-of-school and in-school learning is suggested to be the main challenge to benefiting from non-formal educational learning settings [43].

On an institutional level, non-formal learning environments which are used as places of curriculum development have potential of closing the gap between curriculum development and classroom practice. Thus, initiatives of connecting formal education with such non-formal learning environments are suggested [31]. This approach also allows for opening the formal educational setting.

2.3. Effective Structuring of Non-Formal Learning

For effective structuring non-formal learning, several authors have suggested that the following points are crucial for positive outcomes in out-of-school science education [34,38,44–48].

- Flexible and individually adaptable programs ease the integration of out-of-school activities into formal school curricula.
- A preparatory learning phase in school is necessary to raise effective learning during an out-of-school learning experience.
- Working materials for the out-of-school activities need to be adjustable to the current student's performance and knowledge level.
- The learning environment should be student-centered, inquiry-based, interactive, and provoke cooperative learning.
- After out-of-school activities are completed, the contents and topics covered should be addressed in school again.
- Existing National Science Education Standards or governmental syllabi shall be met.
- Students' and teachers' experience and expectations shall be met.

Other crucial points, not that prominently discussed in the science education literature so far, is that

- Non-formal learning experiences shall meet the expectations of the students and teachers [49].
- The goals of the visits shall be made explicitly clear [38].

Many school groups participating in out-of-school learning experiences are not sufficiently aware of the goals of these visits. Accordingly, the students are unprepared for effective learning [38]. Before

out-of-school learning, the teachers need to inform their students of the learning which is expected from them. The learning success of an out-of-school learning experience depends largely on the teacher's preparation and personal attitude [50,51]. However, teachers are often unaware of their own role during the experience [52].

The staff members and coordinators at out-of-school learning venues must also be aware of the students' and teacher's expectations, preparations and attitudes. Otherwise, an effective linkage of in- and out-of-school learning is difficult to achieve. Anderson, Kisiel and Storksdieck advise people offering field trip opportunities to consider directing their attention towards the teachers' needs, particularly because teachers seem to have multiple objectives [53]. The authors emphasize that both affective and cognitive objectives are the goal of the teachers. Kisiel identified eight general expectations that teachers may have for an out-of-school learning experience [54]. The main motivations for teachers to join out-of-school learning experiences have been identified as: connecting the experience with the classroom curriculum, providing a general learning experience, encouraging lifelong learning, enhancing pupil interest and motivation, providing student exposure to new experiences, providing a change in setting or routine, providing enjoyment, and meeting school expectations and demands (see also [55]). Generally it seems that affective goals seem to be considered as more important than cognitive goals [53]. Contrary to teachers' expectations of out-of-school learning environments, very little is known about the expectations of the students. However, also pupil expectations affect the perception and effects of any out-of-school learning experiences [51].

2.4. Guiding the Development of New Non-Formal, Practical and ESD-Focused Chemistry "Schülerlabor" Environments

All the crucial ideas, discussed in the previous section, were taken as guiding principles to structure the corresponding learning environments for ESD-focused learning environments [49]. Initiative was taken to give non-formal learning a special role in contemporary, ESD-driven practical chemistry education and to elaborate also about the students' and teachers' expectations towards the non-formal learning experience, too.

The initiative started from the understanding that chemistry learning and practical work are inseparably united with each other [56]. Accordingly, experimentation has a key role in any student-oriented chemistry education [57]. However, in the school setting, experiments often have to be performed under difficult conditions: laboratories are frequently poorly equipped, time tends to be limited, the teacher-to-student ratios are often unfavorable, and available experiments are sometimes outdated in content or concerning safety issues and environmental aspects. Much school experimentation still consists of pure teacher demonstrations, which contain no inquiry-based character or hands-on experience for the learners. This makes such "experiments" into mere illustrations of content, but does not perforce lead to challenges of students' thinking patterns [58].

Out-of-school settings have the potential to support a different kind and new orientation of practical chemistry learning [59]. Better conditions for experiments are provided in such situations. Contact to real happening research and innovation in chemistry, e.g., in terms of Green and Sustainable Chemistry, is guiding contention with modern topics and corresponding experimental activities. In Germany, many non-formal laboratory environments for secondary students have been established in recent years at

universities and in research institutes [60]. These laboratories are called “Schülerlabor” (SL), or student laboratories [31]. Over 300 of such laboratories—each with a specific focus—have been founded all over Germany to date [60]. These SLs were established in order to support science learning by offering out-of-school experiences and practical work which is impossible to implement in schools due to a lack of equipment, high costs, or poorly-equipped facilities.

School classes or individual groups of students can use the SLs. The visits are organized by the responsible teacher or by individual students themselves. In general, SL curricula are not necessarily connected to the school curriculum. Since all SLs differ in their orientation and pedagogy, the accompanying research findings are not coherent. It has been shown that SL visits may lead to positive short and medium term effects with regard to levels of interest [61]. In the area of learning outcomes, Itzek-Greulich *et al.* have demonstrated that SLs can lead to improvements [62]. These authors, as well as Zehren, Neber and Hempelmann, concluded that regular SL visits which are strongly linked to formal learning in school will lead to positive effects. In order to maximize the full potential of SLs it is necessary to link out-of-school and in-school learning systematically [63]. Adequate learner preparation and post-experimental processing seem to affect significant positive effects when linked to regular SL visits [61].

The purpose of the study is to develop and implement a new set of non-formal SL learning environments for secondary chemistry education focusing on ESD that were developed informed by educational theory. The second purpose of the study is to get insights into both teachers’ and students’ expectations towards the SL learning environment and how the visit of the specifically developed SL learning environments respond towards these expectations.

3. “Sustainability and Chemistry in Non-Formal Student Laboratories (SLs)”—A Project to Support Curriculum Innovation in Chemistry and Student Learning for Sustainability

3.1. Aims and Scope

“Sustainability and chemistry in SLs” is a cooperative project of two German universities: the University of Bremen in northern Germany and Saarland University in southwestern Germany. The project partners are researchers in chemistry and environmental sciences, as well as curriculum experts in the field of chemistry education. The aim of the project is to develop SL learning environments in the field of sustainability-related issues in chemistry. Half- and full-day laboratory-based learning environments are designed and developed. Topics oriented around everyday life are chosen, which are connected to socio-scientific, sustainability-relevant and industrial chemistry issues. The target groups consist of secondary school science and chemistry classes in grades 5–13 (age range 10–19 years).

The cooperation of the partners was based on each partner developing single modules for the whole range of secondary chemistry classes following a joint structure and then to implement all the modules in both SLs [49]. Exchange and support was provided to each other partner concerning the development of the learning environments and accompanying research tasks. However, each partner took different foci in the evaluation and accompanying research. The topics chosen in the SL at the University of Bremen range from the use of renewable raw materials to man-made atmospheric pollution, biofuels, and modern technologies and synthesis strategies in the chemical industry (Table 1). The data collected

at the University of Bremen focused the expectations and experiences of students and teachers to be reported in this paper while Saarland University mainly focused on cognitive gains of the students.

Table 1. Overview of the topics developed at the University of Bremen and its connection to the aspects of sustainability.

Grade	Module	Sustainability Aspect
5th/6th	Flower and fruit fragrances	Care for resources and the use of renewable raw materials
7th/8th	Chemistry of the atmosphere	Human influences on the planet and its climate
9th/10th	Biodiesel produced from vegetable fats	Sustainable energy generation geared to the future
11th–13th	Synthesis and analysis of vanillin	Assessment of different synthetic pathways regarding the dimensions of sustainability
	Catalysis by zeolites	Modern heterogeneous catalysis for more efficient syntheses
	Click-Chemistry	Modern and sustainable synthesis strategies

3.2. Design of the SLs

The learning environments are characterized by the strong linkage of in-school and out-of-school learning. The development was informed by the crucial points for developing non-formal learning environments in the theoretical background. The learning environments are modular in construction to ensure flexible use and individual adaptability to different learning groups and their corresponding achievement level and prior knowledge. The contents of all the project's learning environments are directly related to the National Science Education Standards and the corresponding regional syllabi. All the modules consist of a set of teaching and learning materials for a preparatory phase in school prior to the visit, as well as suggestions and materials for reflection and assessment. The learning environments are based on a pool of experiments from which teachers can select according to the learning group and teaching/learning objectives.

A student-centered, inquiry-based pedagogy is applied. This approach was chosen because of its potential for students to better understand concepts, develop problem-solving and evaluation skills, and to raise their personal motivation levels [64,65]. The practical tasks selected for the SL learning environment are organized in a learning-at-stations framework to allow for personal choice and flexibility [66]. The learning-at-stations pedagogy is an open learning environment where different experiments and theoretical tasks are offered at different places ("stations") across the laboratory. The students visit the different stations and perform the given tasks. The students work autonomously. The teacher can set different rules of compulsory or facultative stations, time rules, or any hints for a certain sequence. However, with respect to topic and tasks the teacher can also leave all these aspects open to the students. Regularly the students perform the experiments and tasks in small groups to promote cooperative learning experiences. If necessary, certain help cards are available to support student

learning in case of any difficulties. Additionally, the accompanying university staff as well as the teachers are available for any questions.

The activities generally can be characterized as representing a range from guided to open inquiry in order to allow for autonomous learning [67]. Differentiated learning aids are available to support students in their self-directed learning efforts. Structured guidance is available upon request for students of different abilities. This aids learners in completing the different stations successfully on their own or in small groups and brings cooperative learning processes into play. Most inquiry-based tasks are split into steps requiring roughly 15–20 min of time. Failures during inquiry-based experimentation are essential to learning success [68]. The short tasks allow unsuccessful attempts to fully remain within the given time frame.

During the practical work the students are directed by *research booklets*. These include all safety instructions, lab regulations and necessary worksheets. The booklets provide space to outline hypotheses, ideas, sketches, observations and notes. Teachers are also informed about the learning environment with the aid of a small booklet. The teacher manual includes a theoretical introduction, all possible experiments (even those not selected for the laboratory visit), and a selection of worksheets helpful in preparing the visit and to assessing it after the fact. A description of which foreknowledge and skills are necessary aids the teacher in preparing the modules and provides suggestions for how to integrate the experimental section into regular teaching in school.

In addition to the laboratory session, its preparation and the follow-up assessment, each module includes an additional, voluntary element. This non-mandatory part includes a further field trip to research laboratories at the university or within branches of industry that fit the thematic background of the learning environment. The visit is suggested to make the topic more lively and authentic and to allow for career orientation among the pupils.

3.3. An Example in Practice: Biofuels from Vegetable Fats

The coming shortage of fossil raw materials represents a challenge for the chemical industry, as does finding alternatives for fossil-based fuels for reasons of climate protection [24]. Biodiesel was presented as one educationally relevant alternative to conventional diesel fuels several years ago [25]. Manufacturing biodiesel is based on transesterification of vegetable oils and fats with methanol or ethanol in the presence of an alkaline catalyst. Glycerin is produced as a by-product. Biodiesel has a clearly lower viscosity and lower flash point than the untreated oils and can therefore be used as a fuel in conventional Diesel-engines. However, biodiesel is based on vegetable oils and has fallen under increasing criticism because of its competition with regional and world food supply and the fact that its production can cause environmental damage [69]. Researchers quickly recognized these problems and looked for solutions. Alternative raw materials for the production of biodiesel have been found [70]. The production process itself was redesigned into more sustainable form [71]. The process was also improved with regard to the applicability of conventional technologies [72]. These findings make biodiesel more sustainable. However, research efforts are still not finished and continue onward.

Given the importance of this issue, a learning environment for the SL covering how biodiesel is produced from vegetable fats has been created inspired by earlier works, e.g., [25]. It is giving an overall picture of the issue in a form suitable for German lower secondary school students in grades 9/10

(ages 14–16). It includes several experiments to synthesize biodiesel and compare it with conventional diesel fuel (Table 2). The experiments are supplemented by several tasks encouraging learners to think about the necessary characteristics of fuels, societal discussions revolving around the topic, and learning about national regulations such as subsidies.

Table 2. Experiments on the topic of biodiesel produced by vegetable fats.

No.	Experiment
1	Cold extraction of vegetable fats
2	Soxhlet extraction of vegetable fats
3	Synthesis of biodiesel according to the technical process
4	Quick laboratory synthesis of biodiesel
5	Synthesis of biodiesel in micro-reactors
6	Drying of self-made biodiesel
7	Viscosity of biodiesel, conventional diesel fuel and vegetable oil in comparison
8	Flash point of biodiesel, conventional diesel fuel and vegetable oil in comparison
9	Measuring the caloric value of biodiesel
10	Miscibility of biodiesel and conventional diesel fuels

3.4. Evaluation and Accompanying Research

3.4.1. Sample and Focus

Accompanying the curriculum development and implementation, a study was initiated to evaluate the expectations and experiences of students and teachers in the special case of visiting a sustainability-related SL in a chemistry department at the University of Bremen. The study is based on data gathered from teachers and students who were visiting different SL learning environments from within the described project. So far, more than 450 students from grades 5–13 (age range 10–19) have tried out several SL learning environments belonging to the project ‘Sustainability and chemistry in SLs’ at the University of Bremen. Specifically, a total of six learning groups with about 130 students took part in the biodiesel learning environment experience. All participants visited a SL in the time frame between February 2012 and July 2014.

Both teachers and students of all visiting groups were invited to contribute to a survey prior to and after participating in the SL. The first questionnaire focuses on the prior expectations of the participants concerning the visit in the SL. The second questionnaire inquiries into teachers’ and students’ reflections after the visit. 461 students from the whole range of lower and upper secondary science education filled out the questionnaire prior to the visit, and 435 students provided information in the post-questionnaire. All the 37 teachers filled out both questionnaires. Additional characteristics of the participants are given in Table 3.

Table 3. Overview of the sample.

Students			
Gender	No.	Grade	No.
M	207	5/6	198
w	242	7/8	20
No answer	12	9/10	142
		11–13	100
Teachers			
Gender	No.	Professional experience	No.
M	12	<5 years	22
w	24	6–10 years	8
No answer	1	11–20 years	4
		>20 years	3
		No answer	-

3.4.2. Method

The teachers' pre-questionnaire consists of 15 Likert-items and five open questions, while the student's questionnaire consists of 16 Likert-type and two open items. The questionnaire was developed by the research group, discussed with a teacher and piloted with grade-10 chemistry learning group. Likert-items were analyzed statistically. The evaluation of the open-ended questions was done by the method of Qualitative Content Analysis (QCA) as suggested by Mayring [73]. The categories were developed deductively from the theoretical framework, the categories were communicatively validated and applied on the data by two independent persons. Cohen's Kappa is very good, resulting in a value of 0.86 for the students and 0.83 for the teachers.

The post-questionnaires for both groups are similar in construction. The questionnaires consist also of open-ended questions and Likert-items and were developed together with the first questionnaires. Likert-items were analyzed statistically. The open questions were also analyzed using Qualitative Content Analysis (QCA) according to Mayring [73]. These questionnaires focus on the experience made in visiting a very special learning environment. Therefore, the categories were derived from the data in cyclical inductive process as suggested by QCA. In addition, here categories were communicatively validated and applied to the data by two independent coders. Cohen's Kappa returned very good agreement of 0.80 for the students and 0.82 for the teachers.

3.4.3. Teachers' and Students' Expectation towards ESD-Driven Non-Formal Student Laboratory Environments

The analysis of the teachers' answers in the open questionnaire on their expectations resulted in 9, and analysis of the students' answers in 6 priorities (Table 4).

Table 4. Priorities in teachers' and students' expectations on SL visits.

Teachers' Expectations	Students' Expectations
1. Experimental work experience	1. Experimental work experience
2. Additional content	2. Experiencing better laboratory conditions than in school
3. Improvement in attitudes	3. New experiences
4. Ideas for own teaching improvement	4. Better achievement in school assessments
5. Everyday life relevant content	5. Experiences meeting own interests
6. Vocational orientation	6. Vocational orientation
7. Support/relief by supervising staff	
8. Supply of innovative teaching materials	
9. Content knowledge gains	

Nearly 70% of the students anticipated being able to perform a large number of experiments. Thirty-five percent of participants expected the SL to offer better conditions than in school. In particular, the most oft-mentioned aspects from the learner perspective were better lab equipment, more workspace, more time, and no pressure to achieve good marks. In addition, almost 20% of students expected deeper knowledge which could be gained by visiting the SL. All further expectations were of a rather general nature. Of the participants 24% had never visited a SL before and wished to gain new experiences; 17% expected a learning offer that corresponded to their personal interests. Less than 5% of the students mentioned negative expectations about the upcoming experience in the SL.

The teachers expressed quite similar expectations: It was important for nearly 95% of the teachers that their students have the opportunity of experimental work. The teachers also indicated that it is generally difficult for them to conduct experiments in the school environment in both the quantity and quality they desire. Reasons mentioned included insufficient equipment, time constraints and limitations in the school facilities. Both teachers and students were very much aware that conditions in schools are sub-optimal for practical work. About 70% of teachers expressed hope that the SL would complement their own teaching in a reasonable fashion. The teachers acknowledged the SLs offer specific opportunities which are impossible to implement in formal education. A total of 33% of the teachers expected assistance on the intensive preparation generally required for experimental tasks. With regard to practical work, the expectations of teachers and students differed only slightly. The teachers' expectations of content knowledge gains play a much more minor role than they tend to do in students. Only 10% of teachers mentioned an expectation for improvement in their pupils' content knowledge. Instead, almost 70% of teachers were hoping for improved attitudes in their students with regard to chemistry. The teachers also expected benefits for their own teaching, with 45% of the participants hoping to gain new materials and experiments to be used in their own teaching.

In Table 5 analysis of the Likert-scaled questions, which had been filled out after the open-ended questions, are presented and support the findings reported above. The participants were able to express their level of agreement within the Likert-items in a 5-step scale. The agreement decreases with increasing values. The analysis of this part of the questionnaire was done statistically. The low values for Cronbach's α at around 0.7 can be explained by the small number of items asked, however, for scales with few items even these lower values can be considered to be acceptable [74].

Table 5. Teachers' and students' expectations on SLs (Likert-scaled part of the questionnaire).

	Number of Items	Mean	Standard Deviation	Crohnbach's α
Teachers' expectations				
Improvement in attitude among the students	3	1.44	0.43	0.47
Scientific thinking and working methods among the students	4	1.71	0.44	0.64
Gaining content knowledge among the students	2	1.97	0.83	0.79
Expectations for their own teaching	2	2.15	1.00	0.76
Career orientation among the students	3	2.81	1.03	0.83
Students' expectations				
Understanding chemistry concepts	2	2.04	1.04	0.70
Scientific thinking and working methods	3	2.17	0.79	0.56
Career orientation	3	2.39	1.03	0.76
Issues relating to the life	2	2.80	1.30	0.72
Dealing with content knowledge	2	2.97	1.07	0.70

For the teachers, bettered learner attitudes and pupils learning about scientific thinking and working methods were the most important considerations. In contrast, they did not tend to focus on career orientation very much. Understanding chemistry concepts and scientific thinking and working methods were also important for the students. A bit surprising was the discrepancy between the aspects of “*understanding chemistry concepts*” und “*dealing with content knowledge*” among the students. One possible explanation for this is that pupils view the SL as a chance to really understand chemistry, whereas school chemistry lessons are seen as the rote learning of facts without fully understanding them. From the teachers' point-of-view, attitudinal and motivational aspects are the central reasons for visiting a SL, but the students hope for a different type of learning experience based on practical work. Therefore, the Likert-questions support the indications from the open part of the questionnaire.

3.4.4. Teachers' and Students' Experiences towards ESD-Driven Non-Formal Student Laboratory Environments

After the SL visit, there was generally very positive feedback throughout the various teaching modules. A total of 90% of the students and 100% of the teachers returned positive feedback. Eighty percent of the students stated in the open part of the questionnaire that they liked doing experiments autonomously. Of the participants, 35% of the students named certain experiments as particularly interesting. Students also emphasized the importance of experiments for understanding the chemistry behind the topics. Many pupils specifically raised the issues of being given the chance to work independently in small groups and of experiencing intense support by the university staff members. The Likert-scaled part of the questionnaire was mainly thought to provide feedback on the design of the

modules. The results are shown in Figure 1. It turns out that most of the students felt to have understood the material and learning aids. These values improved during the project because the materials were continuously being revised and bettered. The importance of self-directed practical work was supported, as was the case for cooperative learning. Only few of the pupils seemed to have had problems with the guided inquiry tasks and requested more support.

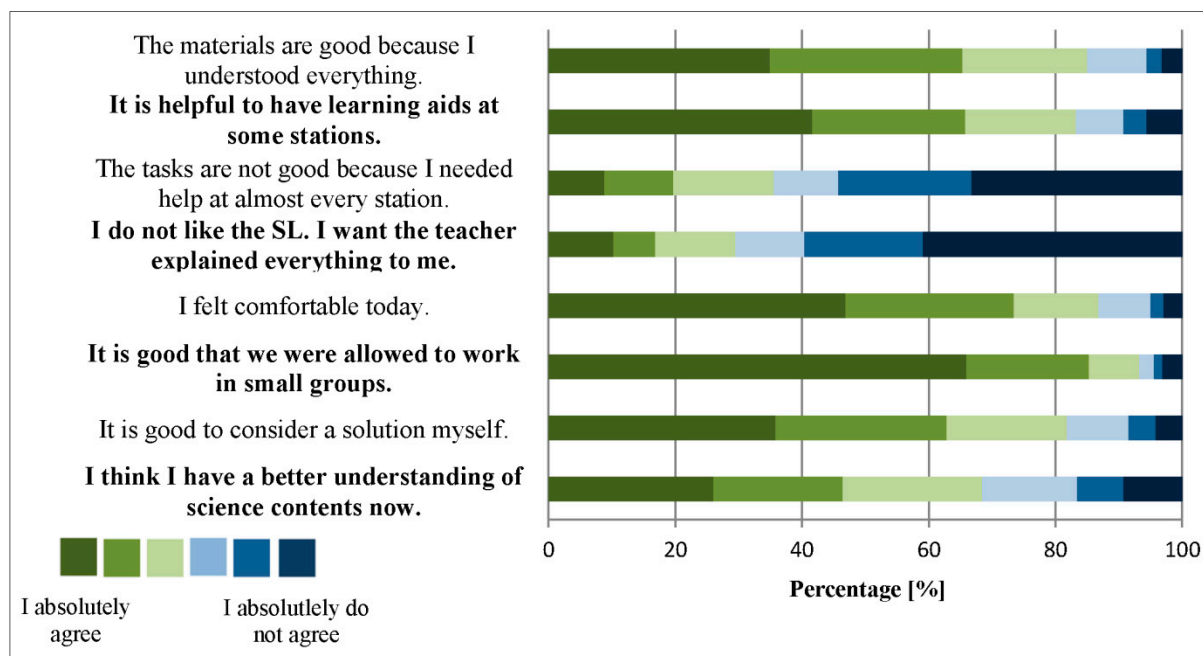


Figure 1. Students' experiences after visiting the SL.

The evaluation of the teachers' questionnaires led to similar results. In the open part of the questionnaire, 75% of the teachers acknowledged that their students had been able to experiment autonomously. About 70% of the teachers emphasized the fact that the materials and experiments were particularly suitable to the topic. Fifty percent of the teachers also liked the additional support provided by the university staff members. In the open-ended questions, many teachers stated that they had followed their students' behavior with great interest. Several teachers also mentioned that they now viewed their students from a completely different angle. Lower-achieving students in particular had surprised their teachers with their work behavior. About 35% of the teachers responded positively to the working atmosphere and the behavior of their students. In the Likert-scaled section, 95% of the teachers expressed positive feedback with respect to the open pedagogy used in the SLs. Ninety-five percent of the teachers assessed the SL as having great potential for promoting scientific thinking and working in their personal opinions. All teachers expressed a feeling that the SL increased the motivation and situational interest among their students. A majority of teachers also indicated that they had absorbed ideas about education for sustainability that they would like to implement in their own teaching.

4. Discussion and Conclusions

Anderson *et al.* suggested that out-of-school learning environments should focus on the needs of the participants if they are to be successful [53]. From the current case study, we can see that a SL covering the issues of sustainability connected to chemistry learning does indeed have the potential to meet the

needs and interests of students and teachers. In SLs, many experiments can be performed which are not suitable in most formal learning environments for various reasons.

All teachers rated the SL-visit positively and indicated that their expectations had been met. Orion and Hofstein have also suggested that more positive student attitudes towards learning science can be achieved by such learning experiences [75]. From the teachers' point-of-view, this was the case. Students' attitudes towards science in general and sustainability-related issues in the context of chemistry had been improved at least at the situational level.

Several authors have reported a low willingness of teachers to implement new teaching materials in their own lessons [76]. Our experience within this project does not confirm this. We found that the teachers coming to the SL were very much interested in integrating both SL learning as well as issues of sustainability into their own classrooms. They were highly interested in receiving new and innovative teaching and learning materials, which could be used in school. From the teachers' point of view, SLs represent a great opportunity to come into contact with new content and curriculum materials, e.g., ESD driven science education approaches. However, these teachers might be composed of a subset of positively-minded and highly interested teachers. Nevertheless, these findings allow a careful suggestion to make more thorough use of SLs for teacher in-service professional development, but also to incorporate SLs in pre-service teacher preparation.

We do not currently have any evidence in which intensity the new ideas and materials were later applied by the teachers in their own classrooms. However, despite the lack of clear evidence, there are some indicators pointing to an initial conclusion that the SL can be a good place for both developing innovations and providing continuous professional development for teachers [31]. The level of interest among teachers for new materials and open discussions about them is one positive indicator. The teachers stated that they had updated their knowledge and that they had also gained new knowledge about sustainability and Green Chemistry. They also expressed the feeling that they had become intimately familiar with the new experiments. Half of the teachers explicitly stated a plan to use these materials in their own teaching. Two other indicators were the numerous times that teachers expressly follow their students' behavior and progress during the laboratory session and the great interest which they express in the development of their pupils' out-of-school behavior. Such a position may offer a chance to reflect upon personal teaching practices and one's own learners with respect to normal classroom experiences in school.

Studies in similar learning environments show that SL experiences usually draw only short- or medium-term attitude improvements. Regular SL experiences have the most potential to lead to sustainable changes [63]. We currently do not have any evidence on this issue in our ongoing SL project on sustainability learning environments in chemistry-related contexts. However, the opportunity to study over repeated visits is there, since various offers exist for all grade levels in secondary schooling. We hope that participating groups of students will come regularly to the SL. This will maximize the benefits which they can derive from their laboratory visits and—in the same time—will allow for new data to inquire into the long-term effects of SLs more deeply. This includes learning about sustainability and chemistry and improving their personal attitudes towards sustainability thinking and corresponding action and research into these aspects.

However, some careful remarks of the findings from this case need to be made. All German SLs (there are more than 300 of them [60]) follow different structures and take different topics into focus.

Not all of them seem to follow the crucial points of effective SLs as derived from the literature above. This especially concerns the connection of the learning environment with the school curriculum, and their adaptability to the individual learning groups, since many SLs are working with fixed programs for all groups of visitors. Thus, it is not clear how the findings from this project fit experiences of students and teachers with other SL visits. In practice, it is also the range of SLs that is limiting the effects since most SLs are available in urban areas where universities or bigger hubs of industry exist. For extending the range of SLs, mobile forms of SLs might be developed. However, this will create new challenges in terms of safety regulations and environmental risks especially for chemistry SLs. It is also not clear to what degree such mobile SLs will have the same effects compared with visits to SLs in authentic environments, like universities or industry sites. Nevertheless, we see rich potential of SLs to both raise student motivation and situational interest in chemistry as well as to contribute to curriculum reform, innovation and teacher professional development, in our case concerning issues and pedagogies related to ESD.

Author Contributions

All authors jointly designed and conducted the project “*Sustainability and Chemistry in Non-Formal Student Laboratories (SLs)*” at the University of Bremen, Germany. Collection and analysis of evaluation data was performed by the first author. All authors contributed to the writing of the manuscript. All authors read and approved the final manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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