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The potential of the non-formal educational sector for supporting chemistry learning and sustainability education for all students – a joint perspective from two cases in Finland and Germany

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Non-formal education has been suggested as becoming more and more important in the last decades. As the aims of non-formal education are broad and diverse, a large variety of non-formal learning activities is available. One of the emerging fields in many countries, among them Finland and Germany, has been the establishment of non-formal laboratory learning environments. These laboratories were established in universities and research institutes to aim at enriching opportunities for primary and secondary school students to do more and more intense practical work, e.g. in chemistry. The primary rationale of these laboratories, in the beginning, was mainly to raise students' interest in the fields of science and engineering, possibly inspiring them to pursue a career in these fields. However, recently the movement has started offering more programs aiming at all learners, but especially those students who are sometimes neglected in traditional science education in the formal sector. A focus on all learners is suggested to help raise students' level of scientific literacy when connecting practical science learning with the societal and environmental perspectives of science. Chemistry learning connected to sustainability issues offers many contemporary topics that are often not yet part of the chemistry formal curriculum but can easily form contexts for non-formal learning. Because of its flexible character, non-formal education can help implementing aspects of sustainability into chemistry education and also can take a gander at the growing heterogeneity of today's students. This paper derives a joint perspective from two non-formal chemistry education initiatives from Finland and Germany focusing education for sustainability for both talented and educationally disadvantaged students in the foreground of a more general perspective on non-formal and sustainability education in chemistry.

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1. Introduction

Over the past decades, non-formal education has become an emerging field in education in general, and in science education in particular (Council of Europe, 2003). There is a continuously growing number of non-formal educational opportunities across Europe and the world (Stocklmayer *et al.*, 2010). While formal learning remains the central pillar of educating the young generation in the sciences, schools are no longer the only place where science education is suggested to take place (Coll *et al.*, 2013). In many countries, such as in Germany and Finland, learning environments, such as science centres and non-formal student laboratories, have emerged to provide additional value to school science education, (Hempelmann, 2014; Tolppanen *et al.*, 2015).

Non-formal educational programs have several aims. For instance, they may aim to raise students' motivation and interest towards science, to orient them towards science-related careers, to provide a broader and more authentic view on science and engineering, or to overcome shortages in school science teaching caused by limited budgets, time constraints, or lack in infrastructure (Stocklmayer *et al.*, 2010; Coll *et al.*, 2013; RSC, 2015). Recently, aspects supporting Education for Sustainable Development (ESD) have also been implemented into non-formal education (Garner *et al.*, 2015), as also the examples discussed in this paper indicate. In this paper, we reflect on two quite different non-formal chemistry education initiatives from Finland and Germany in the foreground of a more general perspective on non-formal chemistry education, namely the focus on all learners including also those commonly not fully reached by traditional formal chemistry classes. The cases are provided by non-formal chemistry learning environments offered by universities,

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namely the Universities of Helsinki and Bremen. In the foreground of these concrete activities, the paper shall provide a perspective on and reflection of the different aims and possibilities of non-formal learning environments that are offered for primary and secondary chemistry education. The reflection includes also the perspectives of enriching chemistry learning with the goals and the contemporary contexts of education for sustainability (Burmeister *et al.*, 2012).

There are several reasons why Finland and Germany were chosen as examples for this joint perspective paper. Non-formal learning, especially learning in non-formal educational laboratories located at universities, has become a very important feature in several countries. Germany and Finland were among them from the beginning. Finland implemented non-formal science education throughout the country in a coordinated approach. In Finland, non-formal education in science, mathematics, and technology-related topics is primarily provided by the LUMA Centre Finland, which operates non-formal learning all over the country in close collaboration with universities, companies, schools and many other stakeholders (Vihma and Aksela, 2014). Finland's national curriculum obliges schools to part-take in out-of-school education (Finnish National Board of Education, 2014), showing the support and formal appreciation for non-formal education on a national level. In Germany, a more decentralized approach to non-formal science learning is operated. Individual non-formal student laboratories in the sciences emerged all over the country to promote primary and secondary science education. Currently, more than 300 of those laboratories, in German *Schülerlabor*, exist (Hempelmann, 2014). Though less formal than in Finland, also in Germany this movement is officially acknowledged and supported by the Federal Ministry of Education and Research, especially when it comes to science learning for sustainability (LernortLabor, 2016). Both countries, but especially Germany, can also be seen as examples for growing heterogeneity and diversity among students, their achievement levels, their cultural backgrounds, and their interests. This is a challenge for more and more countries in the world in times of growing mobility and migration. Like schools, also non-formal education has to cope with corresponding challenges of growing heterogeneity and diversity. It is time to reflect to which extent non-formal education can help the whole educational system to support all students better with feasible science education respecting their different educational backgrounds and achievement levels (Affeldt *et al.*, 2015).

2. Theoretical framing of non-formal chemistry education

Formal and non-formal education

Many studies and political papers state that science education, especially in the chemistry, physics and technology-related fields is unpopular among many students (Osborne *et al.*, 2003; Dillon, 2009; Hofstein *et al.*, 2011; Stuckey *et al.*, 2013). In this context, it has been discussed that many students do not find science education to be sufficiently interesting and relevant

(Osborne and Dillon, 2007, 2008; Stuckey *et al.*, 2013). Many years of reform in science education tried to raise motivation and interest in science learning. These initiatives concerned the whole range of potential changes, in the objectives, curriculum, pedagogy, or media (Eilks *et al.*, 2013). Among the many initiatives there is also the suggestion to re-orient science education by strengthening the non-formal and informal science education sectors and to better connect them to formal education in schools (Coll and Treagust, 2015; Garner *et al.*, 2015; Tolppanen *et al.*, 2015).

Since the early 1970s, many typologies of formal, informal and non-formal education have been suggested (Coll *et al.*, 2013). In 2012, the Organisation for Economic Co-operation and Development (OECD) defined formal education as an organized learning that has a specific structure, is located in formal institutions, *e.g.* school, and is connected to any kind of curriculum. According to their definition, informal learning refers to out-of-school learning which is unstructured and does not follow a specific curriculum (OECD, 2012). Furthermore, informal learning is voluntary and takes place mainly in the students' leisure time. Examples include individual visits to a science exhibit, but it also concerns the consumption of science programmes on TV, reading of science articles found in public media, visiting a museum or a science center regardless of class and teacher (Stocklmayer *et al.*, 2010), but also informal conversation about science-related issues with friends, parents, and peers (OECD, 2012). Typically, non-formal learning is considered to occur out of the traditional school environment, although this does not necessarily have to be the case (Garner *et al.*, 2014). It tends to have a specific structure and is often connected to various types of programmes or curricula (Coll *et al.*, 2013). The UNESCO (2012, p. 10) defines non-formal learning as follows:

“Non-formal learning is learning that has been acquired in addition or alternatively to formal learning. In some cases, it is also structured according to educational and training arrangements, but more flexible. It usually takes place in community-based settings, the workplace, and through the activities of civil society organisations.”

According to Eshach (2007) the main difference between non-formal education, even if connected to official school activities and formal education, is that non-formal education takes place in less formal settings. Furthermore, learning in non-formal education is typically not assessed, and the learning goals are not restricted by any official curriculum.

The distinction between formal, non-formal and informal education is not always easily recognizable, nor straight forward (Garner *et al.*, 2014). For instance, Coll *et al.* (2013) point out that both terms, informal and non-formal, although officially defined and widely used, are often incoherently applied. Quite frequently both terms are indiscriminately used to describe any kind of learning event which takes place outside of school and/or outside the regular curriculum. Furthermore, it is also debatable, whether learning experiences outside the school campus should always be labeled as informal or non-formal education, because they can also form part of the official school curriculum, embedded in the formal learning process, and a compulsory

learning experience for all students. The complexity of distinguishing between formal and non-formal education is also evident when considering non-obligatory courses provided within the schools. Generally, these offerings belong to the formal sector, but due to the fact that they are non-compulsory and not always structured by a specific curriculum, they contain characteristics typically associated with non-formal education (Garner *et al.*, 2014). Regardless of these complexities, in this article we use the term non-formal education to refer to organized science education that happens in out-of-school settings, whether or not it is tied to any structured curriculum.

Possibilities of non-formal chemistry learning

Non-formal – and also informal – education is much less researched than it is the case for formal school lessons (Osborne and Dillon, 2007; Garner *et al.*, 2014). Much of the research on non-formal science education focuses on characteristics of high-quality experiences for identifying appropriate pedagogical approaches. Previous research suggests that non-formal learning experiences in science education can increase student motivation (Wellington, 1990; Csikszentmihalyi and Hermanson, 1995; Jarvis and Pell, 2005), support cognitive achievement (Stronck, 1983; Orion and Hofstein, 1994), improve students' attitudes (Orion and Hofstein, 1991; Rix and McScorley, 1999; Nadelson and Jordan, 2012), offer more meaningful learning (Muscat and Pace, 2013), and provide meaningful social experiences (Anderson *et al.*, 2006; Tolppanen and Aksela, 2013). Furthermore, non-formal learning can offer enjoyable learning experiences and increase students' scientific literacy (Eshach, 2007). Some of the positive effects seem even to persist over time in certain cases (Rennie, 1994; Rhodes, 2013; Tolppanen and Aksela, 2013).

Non-formal educational programs are suggested to play an important and growing role in supporting students' learning. Non-formal learning environments can better provide flexible and individually adaptable programs than school science classes (Rennie, 2007). Working materials can be made adjustable to the current student's interest, performance and knowledge level (Gallacher and Feutrie, 2003). The loose connection to the formal curriculum also gives non-formal education the opportunity to implement issues that are either more specific, or are more relevant for the students in one way or another. Non-formal education gives more freedom of what to teach relating the heterogeneity of learning groups (Hofstein and Rosenfeld, 1996) and includes the ability to integrate multidisciplinary topics and cutting-edge topics, such as sustainability issues, which are currently not implemented in many curricula and syllabi (Garner *et al.*, 2015). Interdisciplinary learning including chemistry, physics and biology contexts may be more easily implemented into non-formal settings.

Student-centered, inquiry-based learning, where young people operate as “researchers”, can help students to understand how scientific knowledge is constructed (NRC, 1996). Such approaches are more easily organized in non-formal education because of better resources, higher flexibility, and additional time (Mantzicopoulos *et al.*, 2008). Therefore, non-formal education

is a good door opener for innovative pedagogies, materials, and inquiry learning (Garner *et al.*, 2015). Student-centred approaches implemented by innovative, creative learning environments can be directly oriented towards students' lives and help them construct knowledge (Affeldt *et al.*, 2015). Linking formal education with informal or non-formal settings can have an influence on the curriculum and pedagogy in the formal educational system by allowing teachers to learn about corresponding teaching approaches in the non-formal educational environment (Garner *et al.*, 2014). Tolppanen and Aksela (2013) suggested that non-formal education also can give students orientation and self-confidence regarding their future careers. Thus, non-formal education provides the opportunity to connect gaining knowledge with interest, learning about authentic societal issues from science-related research, and orientation about professions. All these are essential components of relevant chemistry education as suggested by Stuckey *et al.* (2013). Characterised by a high degree of flexibility, openness to change and innovation in its organisation, pedagogy and delivery modes, non-formal education caters to diverse and context-specific learning needs of students. Thus, there is another benefit of non-formal education. In the context of science for all, activities from informal and especially from non-formal education offer specific chances to learn more or different science than in regular classes in school.

Another contribution of non-formal learning is the role it can play in teacher training (Garner *et al.*, 2014, 2015; Vihma and Aksela, 2014). Non-formal learning activities can be useful in the case of developing teachers' content knowledge and pedagogical content knowledge (PCK). Furthermore, non-formal education offers opportunities for teachers to learn about new developments in science and technology while learning about corresponding teaching approaches, experiments, and pedagogical innovations. In addition, non-formal education provides pre- and in-service teachers a platform to be introduced to topics that are not yet implemented into the curriculum. Finally, teachers can also learn to cope with some of the educational challenges they may face in the near future, for instance, regarding growing heterogeneity and education for sustainable development (Affeldt *et al.*, 2015).

Requirements for success and limitations of non-formal chemistry learning

The effects of non-formal learning seem to depend on various factors. Many researchers point out that careful preparation of visits to non-formal learning environments is important to increase the impact on students' learning (Griffin, 2004; Stocklmayer *et al.*, 2010; Behrendt and Franklin, 2014). In this context, the novelty factor, as suggested by Orion and Hofstein (1994), might play an important role. In this context, the novelty includes the cognitive novelty dealing with the appealed concepts and skills, the geographical novelty relating to the relationship between students and location of the learning environment, and the psychological novelty depending on previous experiences (Orion and Hofstein, 1994). This novelty also makes the explicit linking of inner- and outer-school learning important for

improving motivation and attitudes towards science education (Garner *et al.*, 2014). Orion (1993) suggested a model for the implementation of out-of-school learning into science curricula. In this approach, out-of-school visits are divided into three steps: the preparation in the science classroom, the conduction of the field trip and the subsequent follow-up in school. The preparation-phase is used to raise the effectiveness of the field trip and to lower the novelty space (Orion, 1993). Non-formal learning experiences should not be perceived as detached, unrelated events. They should be incorporated into a preparation-phase and a follow-up teaching phase in school, keeping the novelty effect but not over-demanding the learners (Garner *et al.*, 2015).

Also, Eshach (2007) and Griffin (2004) suggested an intense connection between learning contexts to effectively link non-formal and formal science education so that teachers are crucial for the success of the non-formal learning experiences. If the programme in the non-formal learning environment is not attuned to the learning in school, the students frequently do not connect experiences and knowledge gained in the non-formal setting with their formal learning in school. In their summary of the literature, DeWitt and Storksdieck (2008) conclude that teachers should integrate out-of-school trips into their class curriculum, preview and follow-up sessions during class time, and provide opportunities for students to engage in inquiry-based exploration and hands-on learning while on excursions. A project described by Garner *et al.* (2015) operated a corresponding structure. Findings from this project indicate that visiting non-formal learning environments, *e.g.* student laboratories in the university, have the potential to affect students' attitudes and motivation towards chemistry learning when thoroughly linked to the school curriculum.

Some researchers point out that motivation, enthusiasm, and eagerness can be long-term effects of visiting non-formal learning environments (Rennie, 1994; Rhodes, 2013). Other researchers criticise that benefits of non-formal learning environments are sometimes only of short-term effect, *e.g.* supporting science-related self-concept, knowledge gains, and increasing interest in science (Falk and Dierking, 1997; Wendt *et al.*, 2007; Brandt *et al.*, 2008). Reasons for the limitations in the positive effects of visiting a non-formal setting are suggested in the insufficient follow-up work and a lack of catching up the previously learned contents in school (Brandt *et al.*, 2008). In this context, Wolins *et al.* (1992) have argued that multiple visits and the linkage to the syllabus may help positive effects persist over time. It was also suggested that social interactions in non-formal education can be important, as students can reflect in a more open atmosphere what they have learned with like-minded students, with their teachers and staff from the non-formal learning provider (Rahm, 2004).

With a view to an often discussed achievement gap between students, Rennie (2007) pointed out that non-formal learning environments should be flexible and adaptable to different learning groups so that the programme can consider individual learning conditions. Student groups with a high degree of heterogeneity and diversity make individual advancement in school education often difficult. In a non-formal setting,

the staff–student-ratio is often much better for individual support as there are more tutors per class during the visit than in school. Garner *et al.* (2014) also described that teachers started following individual students' behaviour with great interest. Teachers started seeing their students from a different angle and were often surprised by the working behaviour of the lower achieving students.

Beyond the quality of the learning experience and its inter-connectedness with formal education, the greatest limitation in non-formal learning might be that not all non-formal learning opportunities are available for all students. Non-formal learning environments generally are better available in urban areas, especially those with academic institutions and industry. Educational policy has also to avoid that the visit of non-formal learning environments is to become an issue of availability of financial support. This is to avoid that socio-economically advantaged groups get further advantage by visiting the non-formal environment compared to those groups who are hindered just by a missing budget. Another limitation is that not every subject will be available in every city. Schools from rural areas generally have fewer possibilities to visit authentic research and industry environments, especially related to a specific subject. In such cases, it is at least much more demanding to organize corresponding learning experiences. A potential solution might be to invest in mobile labs that can offer the non-formal experiences in schools or in cooperation with local and regional providers of any other kind of non-formal learning experiences, *e.g.* Youth Centers.

3. Supporting relevant education, teacher training and curriculum development through non-formal education

Non-formal learning as an opportunity to implement new content and contexts

Holbrook (2005) suggests that the key aspect of increasing students' motivation and promoting learning in science is to make science education 'more relevant'. 'Relevance' in science education can be understood in many ways. In a recent review Stuckey *et al.* (2013) discussed the many different meanings of 'relevance' in science education. They suggested science education as being relevant when it makes a difference, potentially having a direct impact on the students' life and future. They suggested that 'relevant' education has several different dimensions. The first suggested dimension is individual relevance, needed to learn skills for everyday life now and in the future. The second dimension is societal relevance, which empowers students to participate in debates about socio-scientific issues and help them to find their role in society. The third dimension is vocational relevance, referring to learning about professions and preparing the students for professional training and work in the future. Thus, in order to make science education relevant, topics have to be chosen that are individually, societally and/or vocationally relevant for the students.

Dealing with authentic and current issues, which are related to the life of children or young adolescents, can have a relevant and motivating character. However, many curricula for formal chemistry education are still quite traditional, neglecting certain aspects of relevant science education, especially the societal dimension of learning, education for sustainability, and many cross-curricular goals (Hofstein *et al.*, 2011; Burmeister *et al.*, 2012; Belova *et al.*, 2016). The curricula and assessment requirements, as well as a lack of time, often results in new topics, such as nanotechnology, climate change and sustainable issues in general, to be implemented into the formal curricula slowly (*e.g.*, Burmeister, Schmidt-Jacob and Eilks, 2013). Furthermore, generally, the adoption of innovations in school often lack both sufficient support mechanisms and recognition of the importance of teachers' underlying beliefs, attitudes and knowledge (Van Driel *et al.*, 2005).

With reforms to improve school curricula taking place across the world, non-formal education has proven to be effective for innovative approaches (Hoppers, 2006). Learning in non-formal settings is not restricted to official syllabi and guidelines (Eshach, 2007). A non-formal learning environment gives the freedom to deal with issues either more specifically, or more holistically, depending on what the students and on what the teachers want. Additionally, it allows the fast and direct implementation of current socio-scientific issues, *e.g.* from the sustainability debate (Garner *et al.*, 2014). It provides the opportunity to deal with relevant, cutting-edge topics that are not yet present in the national curricula or textbooks. New topics, like sustainable chemistry or molecular gastronomy, can be implemented faster into chemistry education because of the flexibility of non-formal learning environments and the corresponding expertise of their staff in universities, research centres, or industry. Furthermore, non-formal learning environments can also give students more freedom and time to dig into these issues and to discuss them from both a scientific and a societal perspective.

In non-formal settings, students can have a deeper learning experience, as they deal with topics that are more closely connected to their daily life than many issues from the formal chemistry curriculum. For example, sustainable mobility offers possibilities for inquiry-based experiments, like synthesis of bio-fuels, inquiry of a hydrogen car model and production of fiber composites or metal foams (Garner *et al.*, 2014; Affeldt *et al.*, 2015). Accordingly, non-formal education can be a way to make science education more relevant and provide the students a better perception of the relevance of science and its related technologies.

Non-formal learning as an opportunity to implement new pedagogies, experiments, and media

Formal learning in school is framed by time constraints, short budgets, and limited infrastructure. School laboratories often do not have the best possibilities for the whole range of student-centered pedagogies and experimentation. Experimental equipment in school is usually less up-to-date than in non-formal learning laboratories and often unavailable at all (Garner *et al.*, 2015). Generally, laboratory work is assigned a central role in any student-centered chemistry education (Tobin, 1990; Abrahams, 2011). However, the positive effect of working in a laboratory on

students' learning is not self-evident (Hofstein *et al.*, 2012), especially if it is restricted to demonstrations caused by insufficient conditions.

Non-formal learning can both offer possibilities for additional experimental learning opportunities and help to develop new pedagogies and materials for practical work for later implementation in school classrooms too (Garner *et al.*, 2015). Non-formal learning, with its greater freedom, also provides the opportunity to try out new activities for a more student-centred pedagogy. They can be more student-centered, inquiry-based, interactive, and should provoke cooperative learning (Eshach, 2007). Non-formal learning environments provide a platform for innovations in the curriculum and its related pedagogy (Garner *et al.*, 2014). The open atmosphere of a non-formal learning environment offers the chance for applying new forms of learning. In this context, the non-formal setting can be a platform for testing inquiry-type experiments before transferring them into school conditions. Out-of-school laboratories have the opportunities to try out different pedagogical approaches for educational content. A better student-to-teacher-ratio gives the possibility to implement more challenging experimental tasks and procedures. Also, non-formal learning environments are often connected to universities and chemistry departments. Thus, the better equipment and the supervision by experienced academic staff allows more flexibility in testing out innovative activities, like new experiments and experimental techniques which are not yet used in formal learning.

Non-formal education gives the chance to try out several variations of different experiments, also with respect to micro-scale and low-cost techniques. Thus, non-formal education can be a door opener to try out new forms of teaching and learning activities and to spread them. The same holds true for approaching chemistry with different contexts, media types, or tasks to see what works best and is most motivating. Instructions for experiments in formal school education are usually more sober-designed. Teachers often do not have the time to develop completely new, creative teaching and learning materials, *e.g.*, instructions for experiments. Non-formal learning environments offer opportunities to try out new forms and designs in teaching and learning materials, *e.g.*, innovative instructions for bringing science closer to daily life. Creative approaches, *e.g.*, experimental instructions in the form of comic books, on-line forums, blogs, and on-line news reports developed in a non-formal laboratory can support students' motivation and help also lowering barriers towards experimental tasks, which are often caused by linguistic deficits among the students (Affeldt *et al.*, 2015).

4. Two cases from Finland and Germany to support students with different needs for ESD in non-formal chemistry learning

Finland and Germany as the cases

In Finland and Germany, there is a fast growth of non-formal learning in science and technology in general and in chemistry

education in particular (Hempelmann, 2014; Tolppanen *et al.*, 2015). In Finland, non-formal learning is primarily supported by the LUMA Centre Finland (Vihma and Aksela, 2014). The LUMA Centre Finland consists of a network of 12 Finnish universities (all science and technology universities in Finland), which collaborate with local schools and the business sector to provide non-formal education for students. There are 12 out-of-school laboratories in different universities from all over the country. The LUMA Centre collaborates with the National Board of Education and supports curriculum work. The main aim of LUMA Centre Finland is to inspire and motivate children and youth into mathematics, science, and technology through the latest methods and activities of science and technology education. This is accompanied by supporting the continuous professional development of teachers working on all levels of education, from early childhood to universities, and by helping implement and develop research-based practices. As an example, the LUMA Centre Finland has organised hundreds of different science clubs and science camps for children and young people since 2003. The oldest out-of-school laboratory is ChemistryLab Gadolin (Aksela and Pernaa, 2009). Another popular innovation has been the international Millennium Youth Camp for talented and gifted students (Tolppanen and Aksela, 2013).

In Germany, a more decentralized movement spread out over the whole country within the last 10–15 years (Di Fuccia *et al.*, 2012). Until today, more than 300 non-formal learning centres for primary and secondary education have been established to support science and technology learning beyond the classroom (Hempelmann, 2014). Most of the laboratories are hosted and connected to universities, larger research centres, or industrial plants. Most of them are today networked by *Lernort Labor*, a joint educational platform for any out-of-school non-formal learning environments for primary and secondary school students (Hempelmann, 2014). In Germany, the name *Schülerlabor* was created for this kind of non-formal student laboratories aiming to promote primary and secondary science education. The name *Schülerlabor* can be translated as student laboratory. The word 'Schüler' in German refers to school pupils exclusively, not to university students (Garner *et al.*, 2014). The *Schülerlabors* were founded in the last two decades, most of them by universities. At first, their primary role was to overcome a shortage in young people embarking into academic careers in science and engineering. Over time, however, the idea of the *Schülerlabor* adapted into a broader movement, with the aim to support science learning on all levels by offering all students out-of-school experiences and practical lab work, possibly now implemented in traditional schools due to a lack of equipment, time, finances, or overall quality in the school lab facilities (Di Fuccia *et al.*, 2012). Quite often student teachers also take part in the *Schülerlabors* as part of their teacher training. *Schülerlabors* are also a place for teachers' continuous professional development (Garner *et al.*, 2014).

The Millennium Youth Camp in Finland – promoting the most talented students

In order to promote sustainability education for especially interested, talented and gifted students, the LUMA Centre Finland held an

international camp between 2010–2014, called the Millennium Youth Camp (Tolppanen and Aksela, 2013). During the camp, 15–19 year-old highly talented students worked in groups of 5–6 students on multidisciplinary projects related to sustainable development. Each year the 30–60 campers were selected from around 1000 international applicants based on previous academic achievements, a letter of motivation and an individual project work. The selected participants began working together online two months before the camp. Each group was initially given reading material, provided by an expert in the given field. Some groups were also given some initial research tasks, requiring 1–2 weeks to accomplish. During the one-week long camp, participants used, on average, 3 hours a day to polish-up their group projects, *e.g.* by practical work. The camp also included a large amount of social activities, such as games and sports, in order to support teambuilding and networking. Furthermore, the camp included other program, such as visiting universities and companies, meeting and discussing with experts, attending inspirational events and preparing for the gala, where the participants presented their projects to experts from universities and companies. The chart below shows how the time was distributed among these activities (Chart 1).

The camp provided students with the opportunity to work on projects related to cutting edge topics, typically not addressed in schools. Examples of these projects include designing a sustainable city, creating an algorithm to make garbage collection more efficient, or examining how the use of ICT can improve literacy in developing countries (Tolppanen and Aksela, 2013; Tolppanen and Tirri, 2014). Many of the projects were related to chemistry. For instance, in 2014, the *Climate change group* examined emissions produced by biodiesel, the *Energy group* examined the efficiency of PEM fuel cells, and the *Material science group* compared the use of gallium arsenide and silicon in solar cells (MyScience, 2014).

One of the reasons for the popularity of the Millennium Youth Camp was that it was created to meet a specific need of a certain group of students, in a way that formal education may not be able to. In the case of the Millennium Youth Camp,

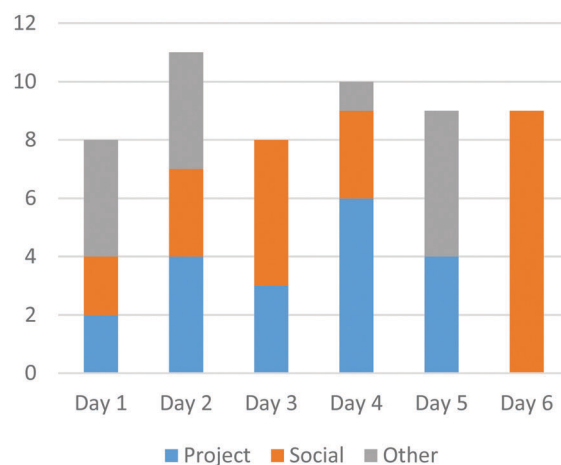


Chart 1 Time used for different activities during the millennium youth camp.

the focus group was gifted students, interested in sustainable development and international relations. However, the aim was not only to provide participants with the opportunity to work on a relevant topic, but also to interact with likeminded students, as well as inspire them by providing the opportunity to meet top experts of the fields they were interested in. These encounters included meeting Shinya Yamanaka, the winner of the Nobel Prize in biology, and Linus Torvalds, the creator of the Linux operating system, found in all Android devices. As the research conducted on the camp shows, attendees felt that the camp met their academic and social needs very well (Tolppanen and Aksela, 2013).

Non-formal educational programs, such as the Millennium youth camp, are also able to deal with timely issues, helping overcome the challenges related to the slow reformation process of national curricula. In addition, they are not constrained by a single topic, but rather, are able to provide a wide range of different topics, helping meet the individual needs of students. At the Millennium Youth Camp, students were able to choose their theme of interest out of ten options, and in most cases, had a strong influence on the research question of the project. All of these themes were multidisciplinary in nature, and would not fit into any particular school subject as such. Furthermore, students were given autonomy over their projects, giving them the opportunity to direct their learning towards their key interests (Tolppanen and Aksela, 2013; Tolppanen and Tirri, 2014). Experts working with the participants felt that the projects helped increase knowledge, but in addition, the projects supported the development of creative thinking and broadening the participants view on academic and professional opportunities (Tolppanen and Tirri, 2014). Experts also mentioned that the projects enabled participants the opportunity to work on timely projects, giving them an idea on what type of issues scientists work on today.

The research conducted at the Millennium Youth camp and other similar programs plays an important part in developing formal education and pedagogical practice. As an example, Finland's new national curricula put emphasis on developing students' ability to live in a sustainable way (FNBE, 2014). This reform gives teachers the freedom to, at least to some extent, freely choose the sustainability topics that they find timely and interesting to students. The studies conducted on the Millennium Youth Camp gives teachers an idea of what sustainability themes students are interested in (Tirri *et al.*, 2012) and how these issues could be addressed in practice (Tolppanen and Aksela, in press).

Chemistry, environment, sustainability in Germany – supporting educationally disadvantaged students

Germany is a country with a particularly high rate of students with a migration background. It also has considerable differences in educational achievements related to the socio-economic, cultural and family background of the students (OECD, 2013). To address the challenges relating to growing heterogeneity and diversity in German schools and to better support students with disadvantaged educational biographies, the project “Chemistry, Environment, Sustainability: Non-formal Learning Environments

for all Students” was launched in a cooperation from universities in Bremen, Saarbrücken, Karlsruhe, and Nuremberg. It uses non-formal learning environments to offer all students the opportunity to develop their understanding of chemistry and sustainability issues (Affeldt *et al.*, 2015). The program aims to provide low achievers and students with disadvantaged educational biographies an environment for learning both about and for sustainability in the context of chemistry-related topics. Supporting this group is essential, as research shows that in Germany it is especially this group of learners that has less developed skills in and attitudes towards issues of sustainability (Michelsen *et al.*, 2015).

The target groups of the project are very heterogeneous secondary comprehensive school science and chemistry classes in grades 5–10 (age range 10–16). A total of six modules has been developed to date. Topics encompass, among others, water quality, alternative plastics, sustainable mobility, and alternative ways of energy storage. Each of the modules offers a set of roughly 20 experiments of which students and teachers can select the ones that suite them best. The project involves a newly developed model of differentiation which intends to include all learners (Affeldt *et al.*, 2015). The differentiation model takes into account students' diversity in their interests, cognitive achievements, problem-solving skills, and linguistic capabilities (Fig. 1). The aim of differentiated instructions is to enable all students to solve each of the tasks on their own. All of the experimental tasks are developed with regard to a student-centered, inquiry-based pedagogy. The experimental instructions are structured to allow students to select a mode, ranging from open to structured inquiry by providing graduated learning aids. The model includes that different tools (help cards) are available to support students at different performance levels. The learning aids are given at the phenomenological-descriptive, the verbal-explanatory, and the sub-microscopic or formal-representational levels. Aside from this, learning aids focusing on content and on the process of inquiry are included. Additionally, aids are provided when dealing with linguistic heterogeneity among the students. Each set of laboratory instructions also contains a set of language-sensitive tools, *e.g.* cloze texts or word lists.

To better connect science learning with real life, as well as to lower the linguistic barrier towards practical work, the developed experimental instructions aimed to acknowledge the way today's students' community. Therefore, comics, blogs and diverse forms of social media, *e.g.*, Facebook, Instagram, and Twitter, were used as elements for the creation of innovative and student-oriented teaching and learning material. The aim was that students would connect situations from their daily life with scientific issues, helping them develop right ideas of natural phenomena. Findings from the accompanying research indicate that students enjoy learning with the created teaching and learning material project (Affeldt *et al.*, 2015).

In the non-formal chemistry learning environment, students are confronted with current and authentic issues related to the fields of science and technology. These issues also provide a platform to discuss the related societal challenges. Furthermore, this project can contribute to curriculum innovation and continuous professional development of teachers, as innovative

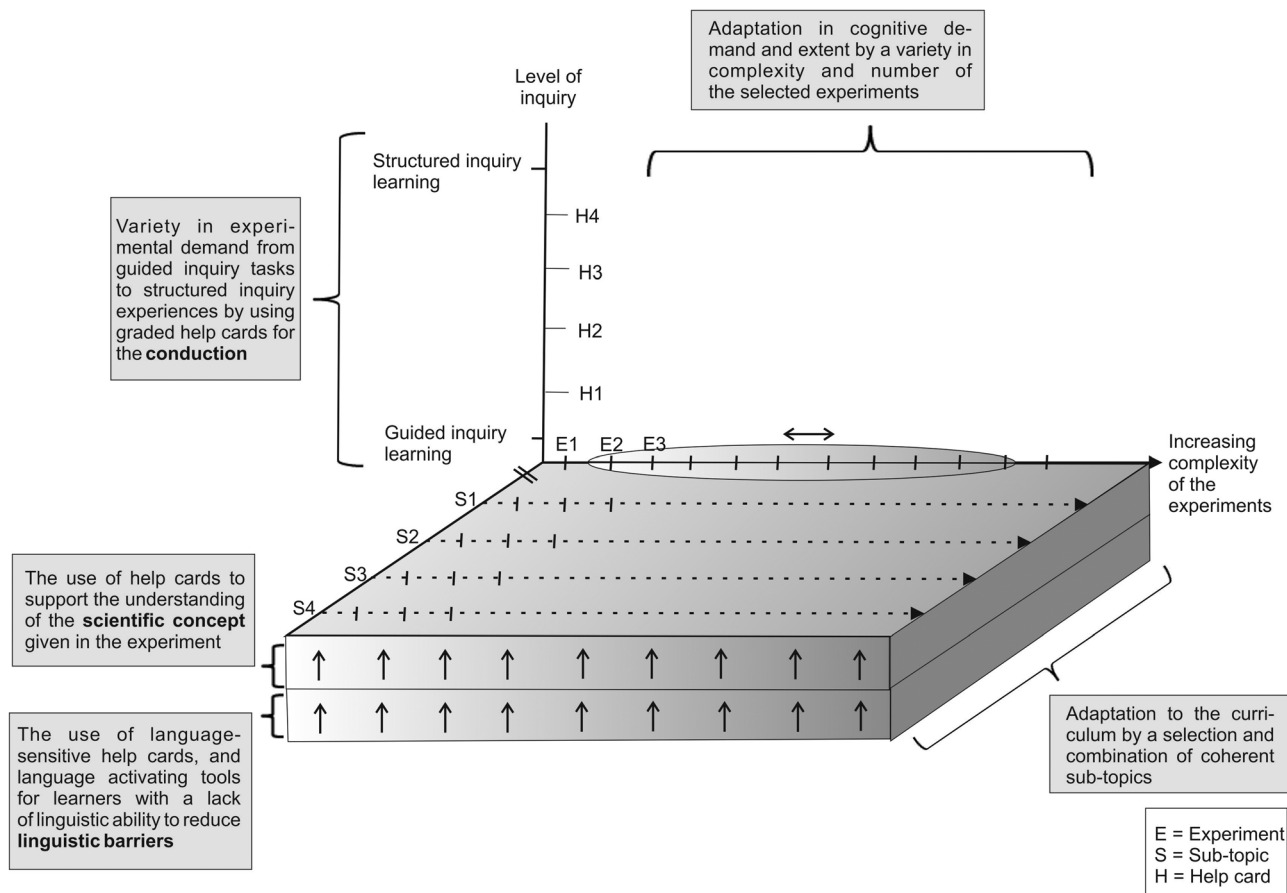


Fig. 1 Model of differentiated learning environments in non-formal education.

and sustainable experimental techniques are developed and are conveyed to teachers in the frame of pre- and in-service education. Networking of schools with the student laboratory is realized in working with selected partner schools and educational institutions outside formal education, like tutoring clubs or local parent initiatives.

5. An educational policy based reflection on the role of non-formal education for chemistry learning and ESD

Educational policy suggests that non-formal education helps develop human capabilities, improve social cohesion, and to create responsible future citizens (Yasunaga, 2014). This suggestion is accompanied by efforts to explore the various roles non-formal education can play in its corresponding educational system and the way in which non-formal and informal education can be most effectively related to formal education. Hoppers (2006) mentions that non-formal education is often defined directly in relation to its function in the context of the whole educational system. Multiple types of non-formal and informal education exist in different conditions (Yasunaga, 2014).

The growing importance of non-formal and informal science learning is suggested in many educational policy documents. Non-formal education has become a policy focus of the international community and is suggested to play an important role in developing lifelong learning, allowing young people to participate in society, today and in future (UNESCO, 2012). This is one big trend in education in many countries, like Finland and Germany.

Another trend is that in increasingly inter-connected and technologically advanced societies internationally agreed goals, such as the Millennium Development Goals (MDG), Education for Sustainable Development (ESD), or Education for all (EFA), have set the agenda for global development. This trend suggests that non-formal and informal education are of growing importance (UNESCO, 2012). This is also seen in the three educational strategic objectives set by UNESCO for 2014–2021 (UNESCO, 2014). The first of these objectives describes the support of member states in developing education systems to foster high-quality and inclusive life-long learning for all. This includes lifelong learning policies and vocational education. The second objective explains the empowerment of learners to be creative and responsible citizens. This includes the orientation in a socio-cultural environment and the participation in a democratic society. The third objective aims at the Education for All. Non-formal science education having a focus

on sustainability education, as it can be seen from the previous sections, provides a great opportunity to contribute to all of the three objectives.

Responsible citizenry for all is a goal also set by the European Union (EU). In the framework of Science Education for Responsible Citizenship, the EU defines key objectives, which shall generate a sustainable effect on the society (European Commission, 2015). A similar concept is integrated into the ideas of Education for Sustainable Development (ESD) (Burmeister *et al.*, 2012). Furthermore, the Science Education for Responsible Citizenship includes the collaboration between non-formal/informal and formal education (European Commission, 2015).

The two examples given above suggest that non-formal education provides unique opportunities to promote science learning and sustainability-related skill development for all students, in chemistry education and beyond. The Millenium Youth Camp was developed to meet specific needs of a certain group of students: talented students, interested in science, technology, sustainable development and international relations. Here the non-formal environment shows its unique opportunity to support the needs of these students, promote learning with like-minded students, and to motivate them to pursue their engagement and future profession in fields of science, technology, and sustainability. A totally different group of learners is the focus in the German project, where non-formal learning activities were created keeping in mind the heterogeneity and diversity of today's students, especially those with disadvantaged educational biographies. The project helps lowering the gap between high and low achievers and motivate all students to engage with science and sustainability with a more holistic approach. It is suggested that even among the students with less advantaged educational biographies, *e.g.* caused by a migration or even refugee background, we can find talents and interested students for careers in science and technology – in the academia or *via* any other vocational training. Independent from the career issue, educational policy suggests that every citizen needs skills for responsibly acting in society and contributing to its sustainable development. This is a goal non-formal education also can contribute to, especially by focusing on less skillful students, who tend to have less developed attitudes towards science and sustainability. However, the innovation does not stop in the non-formal environment, as the new content can be made accessible to teachers and learners, and new pedagogical approaches can be tested and developed, so that they can be later implemented

into formal education more easily. This has already been seen in the German example, as the created model is now ready to be tested in the formal school setting.

In 2012, Burmeister *et al.* described four different approaches for the integration of ESD with chemistry education. These range from a different laboratory practice with less hazardous chemicals, *via* accessing new content, context- and socio-scientific issues-based learning, towards changing school life to innovative practices for sustainability. It is suggested that the non-formal educational sector can contribute to all the four roles. Table 1 suggests selected contributions of the non-formal learning environment that might offer support to the different models suggested by Burmeister *et al.* (2012).

However, non-formal learning in chemistry and for ESD is also, to some extent, limited in range and influence. Non-formal learning and teaching activities are generally only available in urban areas with universities, research institutes, and industry and offer out-of-school learning mainly for learning groups from the regional environments. Thus, not all students have the opportunity to learn in a more varied and contextualised way in the non-formal learning laboratory because of the significant distance to universities in some of the rural areas. The Millenium Youth Camp is not restricted by geographical constraints, but is only able to cope with a very limited number of students. Therefore, many students do not get access to this unique opportunity to learn about science and sustainability, offered by the non-formal learning environments as described in this paper. Furthermore, it is typically up to the teacher whether a trip to the non-formal environment is or can be organized or whether support is given for a successful application to the Millenium Youth Camp. In the case of Germany, there are currently some 8 million students visiting schools at the primary to upper secondary level, however only about 700 000 of them visit non-formal student science laboratories in universities, research centres, or industry per year (LernortLabor, 2016). In the case of the Millenium Youth Camp only 30–60 students from 1000 applications were able to be selected. This observation might remain as long as visits of non-formal learning sites are not made available area-wide and compulsory for all classes on the educational policy level. The approach in Finland by the LUMA Centre Finland is nationwide, however also here it depends on the teachers and schools to which extend the schools can accept the offer to use the non-formal learning environments in chemistry and to which extend. There are also limitations in

Table 1 Contributions of non-formal to support different modes ESD in chemistry education

Model	Contribution from the non-formal educational sector
1 Adopting green chemistry principles to the practice of science education laboratory work	Developing innovative and sustainable experimental techniques in the non-formal laboratory, trying them out in a well-equipped environment, and conveying them to teachers when visiting the non-formal learning environment
2 Adding sustainability strategies as content in chemistry education	Contending students and teachers with current and authentic research in sustainability related fields of proximity to the scientific community
3 Using controversial sustainability issues for socio-scientific issues which drive chemistry education	Confronting students with authentic issues of sustainability currently discussed in science and technology in direct contact with researchers from the corresponding field
4 Chemistry education as a part of ESD-driven school development	Creating innovative structures by systematic networking of schools with the non-formal learning environment as part of school development

innovations in the curriculum and pedagogy as well as teacher continuous professional development by working with and in the non-formal learning environment. Only those teachers being able to visit the non-formal learning environment will have direct access to the environment and can learn while experiencing the non-formal setting with the students. So far there is some research, although still rather limited, on the effect of non-formal learning environments on students' cognition. Concerning the effects on curriculum innovation and teachers' learning in the non-formal learning in chemistry, there is hardly anything known based on research evidence – as is the case with the area-wide distribution of non-formal learning experiences in comparison to urban and rural areas.

6. Conclusion

In this paper, two non-formal learning environments, the Finnish Millenium Youth Camp and the German project “Chemistry, Sustainability, Environment: Non-formal learning environments for all students”, are described. Both initiatives are examples for focussing non-formal learning on students where the formal educational system often comes to its limits. They show how non-formal education can support science learning and ESD to both students with educated and supported talents and those with lower levels of talent or disadvantaged educational biographies.

Curriculum development and development in the pedagogy of science teaching is done in both initiatives by scientists and curriculum experts from chemistry education research. The different learning activities can be linked with the national curricula and syllabi, but also can go beyond, as it is the case in the Millennium Youth Camp. The non-formal education sector, it is suggested, can promote a faster implementation of up-to-date, relevant issues and findings in science and technology than traditional school innovation and syllabus change can do. There are many opportunities in the non-formal settings to develop innovative teaching and learning pedagogies and materials with potential for the adaptation in typical everyday science classes in school, although the process of transfer from non-formal to formal education is an area that needs more research and development. In both of the described cases, the teaching and learning materials were designed based on a research-funded development strategy. However, it is not clear to which extent this is the case for many other non-formal educational initiatives since many of them are mainly reported on an anecdotal basis.

Both projects presented in this paper show a high potential of non-formal learning activities to contribute to the reform of curricula and pedagogy in science education, but it is not completely clear how the formal educational sector might best benefit from the non-formal educational initiatives. However, implementing the lessons learned into formal education is important, as not all schools have the opportunity to benefit from non-formal educational programs, as has been discussed. Another approach to overcome the pitfall that not all students can visit the non-formal laboratories in the universities would be to invest in mobile or virtual labs to allow all students, also in rural areas, the non formal learning experience. However,

in this case research has to reveal whether mobile or virtual non-formal laboratories offer similar potential to the student in terms of motivation and the perception of authenticity.

Concerning ESD, non-formal education is a very prominent sector to help innovate formal science and technology education. Here one needs to ask, will there be similar potential in adopting other important areas of future education, such as, modern materials, current healthcare, or nano-science education, and how this needs to be conceptualized. It also needs to be asked how different providers of non-formal laboratories can better benefit from each other, *e.g.* in the field of ESD. Exchange between the laboratories nationally and internationally as well as adopting programs from one laboratory to another does not seem to be very common yet. Joint activities and reflections as they cumulated in this article, as well as exchange of staff and materials, would support learning from each other. This would also help identifying good practices to be disseminated on a wider scale. For the universities of Helsinki and Bremen this process has already started and it is intended to continue and extend this cooperation with further partners.

In summary, the field of non-formal – as well informal – science and chemistry education is growing. Research based understanding of the corresponding effects and the mechanism is also emerging, though still limited (Osborne and Dillon, 2007; Garner *et al.*, 2014). There is not much research on the long-term effects, nor understanding on how non-formal chemistry learning affects learners with different educational backgrounds. The examples here show that there are positive perceptions and positive short-term effects, both among very talented students, as well as those with disadvantaged educational biographies. However, the focus of research and evaluation also needs to be broadened. Aside from motivation and attitudes, more research is needed on cognitive achievement, skills development, vocational orientation or career success – or the questions of the influence and potential effects of the non-formal educational sector on the curriculum and the teachers. Also, as suggested by Holliday and Lederman (2014), the practices and professional development of staff working in non-formal learning environments is an issue that needs more intense research and research-based development (Holliday and Lederman, 2014). Though there is a lot of potential, non-formal learning should not be over emphasized, as it is difficult to give all learners and teachers the chance for corresponding learning opportunities. This raises the question of whether new types of non-formal learning environments, *e.g.* remote laboratories, that can be visited virtually, are needed. Though non-formal education has increased much in the past years, it seems that the quest for finding best practices and understanding their effects has only started.

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