1. Introduction

1.1 Towards good practice in science teaching

> *'There is little doubt that, in developing student interests and motivations towards science and technology and allowing them to become familiar with the fast-advancing developments in this area, it is essential that science education is part of the curriculum from an early age. [. . .] Science education should form a key part of the primary curriculum. But in recognising that students at this age are unable (and unmotivated) to cope with abstract ideas and tend to gain much from personal involvement activities, the 'hands-on' science education provided is easily accepted by students. Through this approach, it is easy to motivate and interest both boys and girls. This has been shown extensively by science centres across Europe, where the majority of visitors tend to be young children coming either as school groups or accompanied by their parents' (EU Commission, 2004, p. X).*

Ever since the first 'Programme for International Student Assessment' (PISA) focused on science and mathematics performance in 2006, international comparative studies of educational systems have raised concerns about teaching and learning science and mathematics in schools, not only amongst policy makers but the general public. While PISA followed a long tradition of such studies which have been undertaken since the 1950s, such as the Trends in International Mathematics and Science Study (TIMSS, 1995 onwards) or The Relevance of Science Education survey (ROSE), the PISA 2006 survey confirmed a major concern which had been raised by science education experts some years beforehand. Not only did pupils' performance, knowledge and understanding of science appear to be on a much lower level than one would wish for, students also showed less interest and engagement in science or

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scientific careers than was expected in many countries (EU Commission 2004, Sjøberg & Schreiner, 2010; Schreiner & Schwantner 2009; Holstermann & Bögeholz, 2007).

These outcomes challenged the European Commission's goals of becoming the most competitive and dynamic knowledge based economy of the world by 2010 (EU, 2000).

Post PISA 2006, the need to deliver abundant and well-trained human resources for European research has become a matter of increasing urgency and political commitment. In addition, the essential source for a 'knowledge society' is science. Thus becoming scientifically literate is a relevant goal in the general education of all young people, not just for those opting for scientific careers. Understanding science in its rich diversity and being able to act according to this knowledge is a requisite to become a responsible and politically mature citizen.

The European Commission's growing interest in science education policy became most visible in 2007. By then, the 7th Framework Programme funding scheme 'Science and Society' was launched providing € 67m. support for raising student interest in science and careers within in and from science during the following seven years (Lena, 2010).

Two reports laid the pathway for educational projects to work on improving science education in Europe. In 2007, the European Commission published 'Science Education Now, a renewed pedagogy for the future Europe´ (Rocard, 2007). The report became influential in framing the EU 7th Framework Programme 'Science and Society'. In 2008, the Nuffield Foundation published 'Science Education in Europe: Critical Reflections' (Osborne & Dillon, 2008), a report that emerged from a series of workshops involving a group of science education researchers. While the Nuffield Report focused on various aspects of science education and did not emphasise a particular approach, the Rocard Report was explicit in advocating 'Inquiry Based Science Education' (IBSE) as the remedy for Europe's problems. Thus European funding calls focused on implementing IBSE on a large scale in Europe. The distinct role of Learning Outside the Classroom (LOtC) institutions such as zoos, aquaria, botanic gardens, museums or science centres in supporting this approach was explicitly mentioned (Rocard, 2007).

1.2 Collaborative learning at botanic gardens

Between 2005 and 2013, I designed and coordinated two European Projects, the FP6 PLASCIGARDEN and the related FP7 project INQUIRE. Both projects were developed to showcase the role botanic gardens may play in supporting science education reform efforts in Europe.

For many years, botanic gardens and other LOtC institutions have collaborated with schools to provide students, teachers and families with opportunities to expand their experience and understanding of science.

> 'These collaborations have allowed students, and also teachers, to explore, understand, and care about a wide range of natural settings, phenomena, and cultural and historical objects. They have helped students to notice, consider, and investigate relationships between human social behaviour and environmental consequences. They have provided contexts, materials, rationales, and support for students and teachers to engage deeply in scientific inquiry processes of learning. These experiences—with an array of real-life settings, animals, professional science communities, objects, scientific instrumentation, and current research and data—have been shown to spark curiosity, generate questions, and lead to a depth of understanding and commitment in ways that are often less possible when the same material is encountered in books or on screens.' (Bevan et al., 2010, p. 11)

However many LOtC institution, and botanic gardens in particular, do not engage in larger educational reform efforts or in systematic programme evaluation (Phillips et al., 2007) and they often fail to institutionalize collaborations with schools or the educational system. The reasons for this state of affairs are manifold and are often related to the hybrid nature of these collaborations which are both formal and informal at the same time (Bevan et al., 2010). When collaborative teaching and learning programmes are put into practice, they often lack a well-developed theoretical background. This does not mean that the programmes are not successful but a purely practice-based approach stops educators from reflecting on their own practice and developing a professional stance to teaching and learning in LOtC sites.

1.3 Finding a common ground

'Cultural psychology design based research' is applied to understand more about how an imposed theoretical view such as 'implementing inquiry based science education on a large scale in Europe' is interpreted by botanic gardens and natural history museums and whether a collaborative, expansive learning environment has the potential to provide insight where projected ideas fall short through systematic examination of the participant's engagement in an intervention.

> 'Design-based research is premised on the notion that we can learn important things about the nature and conditions of learning by attempting to engineer and sustain educational innovation in everyday settings. Complex educational interventions can be used to surface phenomena of interest for systematic study to better promote specific educational outcomes' (Bell, 2004, p. 243).

Design based research was chosen because it has the potential to contribute to our understanding of learning in complex settings. In this regard, designing and developing an intervention is an explicitly theory driven activity. Through a retrospective analysis it is possible to map:

> '[. . .] the embodiment of particular conjectures through their design reification and to then design research studies to specifically tests the predictions that result. Such predictions pertain to both outcomes expected from the intervention and ways in which designed scaffolds are expected to function. The need to link outcomes to these expected functions across research iterations is the source of power from this analytic approach' (Sandoval & Bell, 2004, p. 200)

My theory driven approach to designing the INQUIRE intervention does not value science education research as the only source. I have additionally tried to learn from organisational behaviour studies to develop a better understanding of what makes change happen.

> 'The ultimate purpose of science education research is the improvement of science teaching and learning throughout the world.' (Abell & Lederman 2007, p. xiii)

Research in organisational behaviour studies the impact that individuals, groups, networks or structures have on behaviour within an organization. The purpose is quite similar to science education research, namely to apply such knowledge to improve an organisation's effectiveness. Educational and organisational research, however, face the same challenge as Abell and Lederman identified in their introduction to the 'Handbook of Research in Science Education' published in 2007:

> 'We must take care that the proximate causes of our research (e.g. achieving publications that count for tenure, writing conference papers so our universities will fund our travel, preparing new researchers getting grant dollars) do not derail us from achieving our ultimate purpose.' (Abell & Lederman, 2007, p. iii).

Whether and how research is still suitable for informing practice is a concern increasingly voiced by scholars in both fields:

> 'I believe it would not be inaccurate to say that the most powerful forces to have shaped educational scholarship over the last century have tended to push the field in unfortunate directions – away from close interaction with policy and practice towards excessive quantification and scientism.' (Condliffe Lagemann, 2001, p. 1)

Splitter and Seidl (2011) argue that:

> 'The generation of knowledge by academics often entails the neutralization of practical urgencies – such as the ability to identify problems for the sole pleasure of resolving them and not because they are posed by the necessities of life'. (p. 106)

Referring to the work of the French sociologist Pierre Bourdieu, Splitter and Seidl assume that:

> 'Social practice performed by individual actors is influenced not only by the actors '*individual disposition*' (such as origin, education and identity) but also by supra-individual '*objective structures*' (such as socially defined interests, beliefs assumptions and resources). Objective structures are not uniform but vary between different social spheres.' (p. 103)

Thus research and praxis are different social spheres, which exhibit different structures associated with different types of knowledge. Actors belonging to one or the other carry out their activities while facing different structural possibilities and constraints, such as being guided by different domain specific interests, beliefs and assumptions and are limited or supported by particular sets of resources. Particular conditions of one or the other field lead to a specific way of observing the world and even the language used. Splitter and Seidl (2011) cite Bourdieu to visualise a phenomenon which is most typical for science education research as it is not understood by practitioners:

> 'Instead of grasping and mobilizing the meaning of a word that is immediately compatible with the situation, we [scientists] mobilize and examine all the possible meanings of that word, outside of any reference to the situation [. . .] The scholastic view is a very peculiar point of view on the social world, on language, on any possible object of thought. (p. 105)

Science education research is often occupied by the monological paradigm of finding the universal laws or structure underpinning a phenomenon. It is predominately seeking to produce the single most coherent model of e.g. 'inquiry based science education', or 'communities of practice' and put significant efforts into examining possible meanings of terms such as 'scientific literacy' or 'pedagogical content knowledge'. By doing this, research runs the risk of overlooking the fact that knowledge is never independent of the social, historical and cultural context that gives it meaning.

An obvious theme, running through all topics addressed in the theoretical framework underpinning my work, is the discrepancy between the researcher's perception of a concept and how this one is constantly misunderstood and modified when it is used and put into practice. I suggest reconsidering the misconception that finding the perfect model is the answer to a problem and consequently helps practitioners to change their practice. I assume that we need to engage people, practitioners and researchers alike, in a dialogical process which asks them to express their everyday idea about e.g. inquiry based science teaching first and then involve them in a process of knowledge creation that is situated in the context in which it takes place. The INQUIRE project gives a practice based example of how involving mixed groups of scientists and practitioners in collaborative knowledge creation processes supports the transformation of knowledge practices pursued in botanic garden education. Improving approaches to support such a transformation of knowledge practices has been the overall goal of this work.

1.4 Overview of my work

As mentioned already, 'designed based research' is explicitly theory driven. Thus the first part of my work provides insight into the complex interplay of different theoretical aspects that informed the design, the structure and the implementation of the INQUIRE project. 'Cultural psychology design based research' in particular is grounded in Vigotskian socio-cultural theory and cultural historical activity theory and focuses on the transformation of mediated action and the cultivation of sustainable learning communities that persist over a longer period of time (Bell, 2004).

In 'Part A: Theoretical Framework', I introduce these theories, as well as 'metaphors of learning' such as learning as a situated, expansive and organisational process.

An overview to the current discussion about concepts such as 'scientific literacy', the 'nature of science, 'science inquiry' and 'Inquiry Based Science Education' gives insight into learning goals the INQUIRE projects seeks to achieve.

This section is followed by looking at concepts of teaching as a profession and the current understanding of what good professional development for teachers should look like. Finally botanic gardens as learning environments are presented and the role of teachers and educators in a LOtC setting is addressed.

In 'Part B: From Theory to Practice', I will give an overview about the INQUIRE project design and our approach to support collaborative knowledge creation. Finally, I will present a case study of two Spanish partners who worked and learned jointly as one 'activity system' in the INQUIRE project consortium. Here Cultural Historical Activity and Expansive Learning Theory are applied as a framework to interpret the significant steps of transformation that occurred during the three year project duration. A special focus is put on partner understanding of Inquiry Based Science Teaching (IBST) and their perception of competence in implementing this pedagogy into their educational programmes.

1.5 Implications

Most of the educational projects that I coordinated over the last couple of years, such as the European 6th Framework Project PLASCIGARDEN, the project 'Forschend Lernen' and the 7th Framework INQUIRE project, were designed to counteract the weaknesses of dealing with the two 'incompatible' social fields of science education research and educational praxis. This was done by supporting botanic gardens or LOtC institutions to develop either national or international 'communities of inquiry' and to establish a network of professional learners engaging in European educational reform efforts.

As project partners, botanic garden and natural history museum educators are asked to engage in collaborative knowledge creation (Moen et al., 2012) and create a domain specific understanding of how to engage with education research knowledge, generate, incorporate, evaluate, and adapt the best of the specific new ideas and practices that emerge amongst them as a group of learners and thus develop a theory of Botanic Garden learning.

This monograph is dedicated to providing a rational and theoretical basis for LOtC institutions to engage in the science education reform efforts and rely on collaborative knowledge creation processes for developing a better understanding of 'good science teaching and learning at botanic gardens' while adapting a theory-informed, critical and reflective approach to teaching and learning.

Based on this work, I believe that there is not only a need for new approaches to learning

> 'especially for understanding and supporting practices where people are creating or developing useful and reusable things in collaboration' (Moen et al., 2012, p. ix)

But also a need to recognise collaborative learning processes taking place on different levels as important assets when evaluating European funded projects.