LEARNING FROM INNOVATION AND NETWORKING IN STEM (LINKS)

EXPERIENCES IN IMPLEMENTING EFFECTIVE CONTINUOUS PROFESSIONNAL DEVELOPMENT FOR STEM TEACHERS IN FIVE EUROPEAN COUNTRIES

LINKS
Learning from Innovation and Networking in STEM

Coordinators per country (in alphabetical order),

Doris Arztmann, Austria
Risto Leinonen, Finland
Anna Pascucci, Italy
Frédéric Pérez, France
Andrew Thirlwell, United-Kingdom

Authors (in alphabetical order)

Maija Aksela
Tracey Baxter
Paola Bortolon
Karen Brunyee
Claire Calmet
Laurence Constantini
Matt Cornock
David Craven
Frances Dainty
Cédric Faure
Laurence Fontaine
Maria Angela Fontechiari
Andrea Frantz-Bittner
Gill Gunnill
Julia Halonen
Jaana Herranen
Pekka E. Hirvonen
Karen Hornby
Irina Kudenko
Minna Korhonen
Jérôme Lambert
Mark Langley
Anne Lejeune
Adam Little
Tom Lyons
Elena Pasquinelli
Johannes Pernaa
Tuula Pesonen
Antoine Salliot
Clémentine Transetti
Murielle Treil

All partners of the LINKS project would like to warmly thank the following persons who accepted to provide their feedback on this document:

Critical friends (in alphabetical order),

H.M.C. (Harrie Eijkelhof, Utrecht University, the Netherlands
Cliona Murphy, Dublin City University, Ireland
Christel Op de Beeck, Flemish Ministry for Education and Training, Belgium
Marco Signore, Stazione Zoologica Anton Dohrn, Italy
Barbara Streicher, Science Center Network, Austria

This publication is funded by the Erasmus + Programme of the European Union.

Erasmus+

LEARNING FROM INNOVATION AND NETWORKING IN STEM (LINKS)

EXPERIENCES IN IMPLEMENTING EFFECTIVE CONTINUOUS PROFESSIONNAL DEVELOPMENT FOR STEM TEACHERS IN FIVE EUROPEAN COUNTRIES

Table of contents

List of abbreviations

ANISN: Associazione Nazionale Insegnanti di Scienze Naturali - Italy

CBL: Context-Based Learning

CERN: European Organization for Nuclear Research

CPD: Continuing Professional Development

ECTS: European Credits Transfer System

ES: Education for Sustainable Development

IBL: Inquiry-Based Learning

IBSE: inquiry-based science education

IMST: Innovations make schools top - Austria

ICT: Information and Communication Technology

ITT: Initial Teacher Training

LHC: Large Hadron Collider

LINKS: Learning from Innovation and Networking in STEM

LUMA: Matural sciences (LUonnontieteet) and Mathematics (MAtematiikka) - Finland

MOOC: Massive Open Online Course

MPLS: Maisons Pour La Science (Houses for Science) - France

NEP: NaturErlebnisPark Science Education Centre - Austria

NGO: Non-Governmental Organisation

NoS: Nature of Science

STEAM: Science, Technology, Engineering, Arts and Mathematics

STEM: Science, Technology, Engineering and Mathematics

OECD: Organisation for Economic Co-operation and Development

PCK: Pedagogical Content Knowledge

PFL (in German): Pedagogy and Teaching Didactics for Teachers

RECCs: Regional Educational Competence Centres (Austria)

RRI: Responsible Research and Innovation

SCK: Subject Content Knowledge

RCUK: Research Council Cutting Edge Science programme in UK

SID PROJECT: Scientiam Inquirendo Discere project - Italy

Foreword

The LINKS project (Learning from Innovation and Networking in STEM - science, technology, engineering and mathematics), funded by the Erasmus + programme of the European Union and coordinated by the Fondation *La main à la pâte* (France) is carried by a partnership composed of 9 institutions involved in STEM Continuing Professional Development (CPD) of teachers and their educators in five countries: Austria (IMST/NEP), Finland (LUMA Centres), France (*Maisons pour la science*), Italy (ANISN) and the United Kingdom (STEM Learning). They belong to (and some of them coordinate) national networks which all together represent 120 local CPD providers.

These national networks share the same convictions:

1. **The challenges of our time require the consideration of the role of broad science and technology education** as a basis for securing the innovation potential and the sustainable social and economic development in Europe. This involves increasing public understanding of science, interest and motivation for innovation, civic competencies as well as the achievements of students in STEM (science, technology, engineering and mathematics).
2. **For the crucial task of preparing young people to live in a complex world marked by rapid change, key players are teachers.** Just like their students, they need to constantly learn and develop their skills.
3. **Continuous Professional Development is the most effective leverage to support teachers** in their task and enhance the quality of STEM teaching.

However, to make the most of CPD benefits, it is crucial to design and implement programmes that target effectively the needs of teachers. LINKS partners, in their diversity, actually share a number of similarities in terms of content, formats and the organisation of professional development, that draw the lines of such programmes, in any peculiar context.

Finally, they also share a similar intermediate position as network structures that connect teachers, schools, researchers, pedagogical sciences, science studies, economy and the public authorities for the sake of the qualification of teachers.

Thanks to this position, LINKS partners take up another key challenge which is the commitment of decision-makers in the support to the expansion and sustainability of proposed CPD strategy.

The principal objective of LINKS project is therefore to develop a network focused on systemic change, in order to propose to their main targets (CPD providers, local and national governments, employers, the scientific community and the European Commission) long-term strategies to answer this central question: **what should be considered –and thus promoted and supported- as innovative, effective and sustained STEM CPD programmes?**

For that, the partners collate and share practices on the design and implementation of impactful CPD in their country, share experiences on five cross-cutting issues conducive to successful CPD programmes, and have the objective to disseminate the outputs of the project to enhance the mobilization of various stakeholders. The 5 cross-cutting issues targeted within that project are the following:

- working with the schools,
- working with the scientific community,
- working with the employers,
- quality assurance and evidence-based impact evaluation,
- building comprehensive partnerships and alliances.

The first step of the network's work was to propose **a common framework for STEM CPD based on the experience of the 5 national networks and to draw some recommendations for its implementation**. This took the form of a capitalisation of best practices which is the core content of this study that analyses conditions for innovative and successful CPD on the basis of activities and programmes that have been developed within qualification networks and that have proven themselves beneficial in different European countries.

1

Introduction

1.1 Rationale of the study: STEM Education in a Changing World

The main intention of teaching has always been to support children and young people in the acquisition of skills and competencies they need for a successful personal life and their responsible participation in society.

Global trends of the beginning of the 21st century pose manifold challenges to teachers that cannot be met by previous means and methods of the profession. In a rapidly changing society characterised by globalisation, technical innovation, digitalisation and social upheaval, classic subject teaching is getting aware of its limits. Furthermore, educational policy makers expect schools to foster a holistic personality development covering cognitive, physical, social and cultural aspects.

The educational systems should prepare the next generation for a life in an increasingly complex world, where knowledge, skills and expertise are key for a successful participation in the global economy.

1.1.1 The challenges for STEM education

STEM education and sustainable development

According to the UN (United Nations) Sustainable Development Goals "all people may have access to lifelong learning opportunities that help them to acquire the knowledge and skills needed to exploit opportunities to participate fully in society and contribute to sustainable development" (A/70/472/Add.8 - United Nations Decade of Education for Sustainable Development: Report of the Second Committee, Dec.2015). The overall aim is to "ensure responsive, inclusive, participatory and representative decision-making at all levels" (A/RES/70/1 - Information and Decision -Making, Institutional Arrangements, International Cooperation, Sept. 2015).

The LINKS partnership agrees that these guidelines should be considered in designing and implementing CPD programs. The partnership fully supports teachers' individual evolvement as well as teachers' involvement in communities through materials and methods that enable active participation and collaboration. Engaging in educating the educators activities, we see considering and responding to teachers' needs as key to meet these goals.

These developments result in relevant changes in the way scientists work. More than ever the profession faces the needs to contextualize scientific research within societal systems. Research ethics and questions regarding the greater good of scientific knowledge are most relevant. In all scientific disciplines, we find a claim for "Responsible Research and Innovation" (RRI). Scientific communities regard a multi-perspective approach on research topics and interdisciplinary scientific cooperation as promising frames to deal with complex environmental and societal problems.

Considering these far-reaching trends and transformations, Europe faces severe challenges to ensure its sustainable development of society, economy and ecology. Europe´s educational systems are obliged to offer adequate structures to enable young people to tackle these and future challenges.

Responsible STEM education therefore considers social contexts of scientific contents. Some national curricula face this challenge by turning towards more holistic and interdisciplinary didactic settings while others include aspects of social learning, multi-perspective views and personality development into subject curricula.

STEM education and citizenship

Recent societal challenges for STEM CPD pose political discourses that claim "alternative facts" or dispose of theories like Darwin's Evolution theory. Movements like "March for Science" take a stand against anti-science agendas and policies. They are based on the conviction that science as a tool for seeking broadly discussed, theoretically and empirically proved answers is essential for a democratic society. To counter current post-truth attitudes, as scientist Antonio Gomes da Costa puts it, CPD efforts need to strengthen science based validation criteria as opposed to authority based ones:

"This post-truth attitude has dreadful consequences: democracy assumes – requires, actually – that decisions made by the citizens are based on factual evidence and rational choices. Our contemporary societies, our well-being, our progress, health, economy, and justice, all require truth and facts and logic to be the basis of our collective actions and decisions. Post truth is a serious threat to democracy. [….] We need to help citizens grasp the difference between authority-based and science-based validation". (Gomes da Costa 2017)

We share the vision that scientific literacy is a basic precondition to participate in social structures and processes. Socially engaged STEM education encourages critical discourse and democratic acting[1]. In our efforts, we LINKS partners strive to connect logical-analytic insights with other, qualitative forms of cognition as well as with ethical considerations in order to maintain dialog-ability in an increasingly heterogeneous society. Thus, we aim to foster complex civic competences.

[1] Bartosch, I, Lembens, A. (2012). Naturwissenschaftliche Bildung: ein Menschenrecht!. In *IMST Gender _ Diversitäten Netzwerk (Hrsg.): Gender _ Diversity-Kompetenz im naturwissenschaftlichen Unterricht. Fachdidaktische Anregungen für Lehrerinnen und Lehrer*. Klagenfurt, Institut für Unterrichts- und Schulentwicklung.

STEM education and the economy

During our LINKS twinning meetings, we repeatedly met employers complaining about an educational system that leads to young people leaving school without acquiring the necessary competencies to start their working life. A changing world of employment increasingly requires crossover skills. Employers seek workers who take initiative, think critically, solve problems creatively, innovate, are capable of working in teams, communicate clearly and successfully process a flood of information. To frame these needs related to economic and social well-being, OECD refers to a framework developed by the Partnership for 21st Century Skills (P21). The so called "21st century skills" serve as a central guideline with extensive implications for schools and the ways children and young people learn and are being taught. However, these 21st century skills go beyond the question of employability of a (future) workforce.

STEM education for all students

With the rapid development of Europe's knowledge economy and new technologies on the rise, it is important to attract and keep more people interested in STEM studies. The goal of including all students, whatever their gender, age, abilities, socio-economic background or culture is paramount, especially, as recent studies still indicate a severe gap in participation when closer looking at interest rates in STEM fields. Facts and figures evidence a disadvantage for socially marginalised groups (PISA 2015, Danish Technological Institute, 2015). For one, research indicates a gender-gap throughout Europe. Often termed as a (leaky) pipeline issue, its effect is that fewer girls than boys choose to study STEM subjects at secondary school and university. The pervasiveness of gender stereotypes that prevent girls and young women from choosing and thriving in STEM is another, often-highlighted reason for this bias. For example, research shows that girls and boys internalize gender norms at the *individual* level from an early age on. This means that when they encounter STEM education activities, they already have well-established gender identities that encourage a seemingly natural affiliation with STEM fields for some while for others STEM attachments are socially discouraged. This again means that to avoid feeding into a sense that study fields are 'not for them', CPD activities should be carefully designed to be inviting to everyone, irrespective of their entering knowledge, interests, experiences, and sense of identity (Nagy, 2009).

When looking at research however, meta-analysis (Guiso and colleagues, 2008) consistently show that girls and boys are on average much more similar than they are different across a range of skills. For instance, a research conducted in 2008 by Guiso and Monte (ibid.) in gender differences in mathematics found that girls outperformed boys overall in primary school. Additionally, there was no difference in secondary school and there was only a very slight and inconsistent male advantage for complex problem solving.

The international standard test PISA brought to light that even though gender differences in science performance tend to be small, on average, in 33 countries and economies, the share of top performers in science is larger among boys than among girls. Finland is the only country in which girls are more likely to be top performers than boys. In the 2015 PISA study, the average difference between high-achieving boys and girls was 19 points. This is roughly the equivalent of about half a year at school. When factoring in reported levels of self-confidence or anxiety towards mathematics however, these differences disappear according to the study. On average, girls were more anxious about tests than boys were, and this seems to have affected their score. Research from these different perspectives converges on the idea that there is little to no difference in boys' and girls' average ability at STEM subjects. However, PISA numbers also elucidate that on average across OECD countries, and after considering their socio-economic status, immigrant students are more than twice as likely to perform below the baseline level of proficiency in science as their non-immigrant peers. (Pisa, 2015: 4). In order to attract students and to encourage them to thrive in STEM subjects, CPD activities need to tackle the gendered and socio-economic stereotypes students and teachers are exposed to and (unwillingly) tend to pass on. Especially at a time, when science literacy is increasingly linked to economic growth and is necessary for finding solutions to complex social and environmental problems, all citizens, not just future scientists and engineers, need to be willing and able to confront science-related dilemmas.

STEM CPD should urgently take on this challenge by scrutinizing its own activities for making STEM education a more inclusive project for students and for optimizing those science experiences to be accessible to an even broader range of actors: within teaching and studying STEM alike. This way, inclusive endeavors to STEM teaching and learning can help old and young people get a deeper and more nuanced understanding of what STEM study fields entail, and allow them to make better-informed choices about their fields of (prospective) interest.

References:

Guiso, L., Monte, F., Sapienza, P., Zingales, L. (2008). *Culture, Gender, and Math*. In Science, June 2008. DOI: 10.1126/science.1154094.

Nagy, G. (2009). Forschungsprojekt „*Geschlechteraspekte in der schulischen Leistungsbewertung*“ Teil I: Bericht. Verfügbar unter: https://bildung.bmbwf.gv.at/schulen/unterricht/ba/vs_fb_t1_21126.pdf?61ecim [17.02.2018]

PISA. (2015). *Results in Focus*. Online Ressource http://www.oecd.org/pisa/pisa-2015-results-in-focus.pdf Download 04.05.2018.

1.1.2 How to address these challenges?

The need for new educational patterns for children and teachers as well

Considering the importance of action-oriented, situated and problem-oriented teaching methods, there is a large degree of consensus among the LINKS partners that inquiry-based science education (IBSE) in particular offers good conditions to foster personality development among children (e.g. it fosters problem solving, creativity, cooperation, communicative abilities), supports reflecting on individual every-day decisions and contributes to responsible citizenship.

In addition, we aspire to broaden inquiry-based educational settings by including perspectives of humanities, economy, language teaching, etc. to enable lifeworld orientated teaching and learning. In LINKS, we found a broad spectrum of implementations that support embedding IBSE activities into a global view of social and environmental responsibility and change.

With IBSE activities, educational action research and further CPD activities within STEM, we do not only intend to promote academic competencies but also aim to foster dialogue and debate capability, evaluation and reflection skills, ambiguity tolerance and informed and community contested truth seeking as basic civic competencies as described in concepts of “scientific literacy.”

OECD defines scientific literacy as the capacity to use scientific knowledge, to identify questions, and to draw evidence-based conclusions in order to understand and help make decisions about the natural world and the changes made to it through human activity.

“School science education contributes to the broader goals of education by providing students with a scientific understanding of the natural world through knowledge of the basic concepts of science, scientific modes of inquiry, the nature of the scientific endeavour, and the historical, social and intellectual contexts within which science is practiced. The ability to apply such scientific knowledge to aspects of one’s personal and civic life is referred to as scientific literacy.” (Bybee & Trowbridge 1996)

According to Gräber et al. (2007): scientific literacy consists of three dimensions:

- knowledge (language competence, epistemological competence),
- agency (competency, communicative competence, social competence, procedural competence),
- and evaluation (ethical-moral competence, aesthetic competence).

This means that for us the goal of STEM education in the end is to foster broad civic competencies that enable to draw conclusions based on informed debates.

A way forward: fostering innovation

Innovation is an “evolutionary” process. Being aware of the continuously changing constitution of our natural and social environment in an ever changing development (in Piaget’s words modulating between “adaptation” and “assimilation”) it is necessary to keep an institution in a vivid relation with its contextual framework. Adapting to an actual situation or challenge can be achieved either by modification of established methods or by breaking totally new grounds.

Innovative institutions therefore are characterized through “iterative, continuous and flexible processes of adaptive learning” (Owen 2013) taking place in circles of action, reflection and development. Ethical foundations and their constant re-negotiation are paramount. Questions like the following link innovation to participation, informed citizenship, community building and equal opportunities: Whom will these innovations serve? Who is taking part in their shaping? Who is absent? What will the benefits and costs of these innovations be? How sustainable are its effects?

Innovation in this sense of inquiry and activity is resonant with the basic approach of Action Research.

Regarding the actual discourse about responsible research and innovation (RRI) “innovation” has a dual significance for our work.

First we strive to be innovative in our methods, settings and approaches to tackle actual challenges. Second, our activities aim to foster students’ attitudes, competencies as well as their creativity to face the need for innovation they will meet in almost every walk of life (see: Europe 2020 Flagship Initiative - Innovation Union).

References:

Bybee, R.W. & Towbridge, L.W. (1996). *Teaching secondary school science* – Strategies for developing scientific literacy (6. Ausgabe). New Jersey: Prentice-Hall Inc.

Gomez Da Costa, A. (2017). *From Ear Candling to Trump: Science Communication in the Post-Truth* World. In: SPOKES # 27.

Gräber et al. (2007). *Scientific Literacy: Der Beitrag der Naturwissenschaften zur Allgemeinen Bildung. Leske und Budrich Bybee*, R.W. & Towbridge, L.W. (1996). Teaching secondary school science – Strategies for developing scientific literacy (6. Ausgabe). New Jersey: Prentice-Hall Inc.

Krainer, K. (2003). *Journal of Mathematics Teacher Education*. 6: 93. doi:10.1023/A:1023918616310

Meyer, M. and Kearnesm. M. (2013). *Introduction to the special section: Intermediaries between science, policy and the market*. Science and Public Policy, 40, p.432-429.

Owen, R., Macnaghten, P. M., & Stilgoe, J. (2012). *Responsible Research and Innovation: from Science in Society to Science for Society, with Society*. Science and Public Policy, 39(6), 751-760.

1.2 Methodology and methods used to draft the study

Using a qualitative content analysis approach (Mayring, 2014), this study aims at describing and understanding experiences made and documented within the various national STEM education networks.

The objective of this study is to capitalise and analyse processes of STEM CPD best practices developed by partners in their national networks. In engaging and discussing common trends and issues with related European networks in the field, ultimately we want to suggest next and future steps in developing innovative and sustainable STEM education policies and networks.

With this aim in mind, a key methodological framework we draw from is the critical friends’ method. Developed in the Annenberg Institute for School Reform at Brown University in 1996 (Dunne and Honts, 1998), the Critical Friends model for collegial dialogue aims at fostering reflective learning within educational settings. In addition to its implementation within schools and universities, it is now also applicable as a model of organisational learning or learning in networks. In the initial stages of this model, some practitioners have expressed their concern that the “critical” in critical friends will lead to the depreciation of colleagues’ work. Within this model, however, “critical” implies “crucial,” “essential,” or “significant”—in other words, colleagues participating in this process are eager to provide important assistance to professionals in a shared field of expertise. Through analysis and critical advice, everybody involved collectively develops strategies to improve the organizational learning of the home as well as the host context. Costa and Kallick (1993) describe a critical friend as a trusted person who asks provocative questions, provides data to be examined through another lens, offers critiques of organisational work and takes the time to fully understand the context of the work presented and the outcomes that the group is working toward.

To produce the study, the partners went through a process of deep mutual understanding of what is realised in other countries thanks to specific meetings (‘critical friends’ meetings).

Indeed, all partners have taken part in some transnational meetings for the purpose of sharing their practices in STEM CPD. During these meetings, the organizer presented to participants its experience focusing on the expertise and the innovative aspects developed in the specific context. Questioning and exchanges between participants, after visiting an illustrative activity, sought the identification of best practices both during the meeting and after.

These visits were organised among sub-groups of countries, to allow for an extensive first stage of comparison in order to draw some lines for the study. Once the process of ‘critical friends meetings’ was completed, reports of each visit have been analysed and the final plan of the study was produced for further writing (See the flow-chart on the following page).

We developed a template for compiling the necessary information for each network. Amongst others, the template requested to collect data on the following indicators: information on the funding, the source of information on the networks including overall aims and objectives, the design of the conducted fields of work within CPD, as well as information on the addressed fields of STEM and on the geographical scope. One factor becoming a challenge for this cross-national analysis was the variation of languages. As most of the findings from national projects were only available in the respective national language, partners had to translate and provide the info in English as our common language. The template was used to offer first-hand information on the partners' situation. The second purpose of the template was to guide the analytical focus of the visiting partners as critical friends.

After the field visits and exchanges between partners some key issues were identified as common to all partners. Not all are developed with the same extent in all countries, but all together they draw the picture of the main characteristics developed by all partners to address the issue of quality CPD.

The draft has been revised by all partners and submitted to a pool of "external critical friends" then finally edited. An executive summary of this first output of the project was produced by *La main à la pâte* for the purpose of paper edition in all languages of the project (translations in French, Italian, German and Finnish, done by partners themselves). The full study is available online, in English.

Some important points concerning this study

The heterogeneity

The merging meta-analysis of the individual LINKS systems of partners forms the basis for common visions, potential development guidelines but also the pointing out of regional and structural heterogeneity.

Analysing data on the reported experiences, we looked at issues across various national contexts. In doing so, we came across linguistic boundaries and different scientific and application-oriented cultures, we had to question the equivalence of concepts and terms, and we faced difficulties regarding the consistency of data because there are interferences due to differing contexts of application. All these factors moderate the actual comparability of findings. Nevertheless, working with the differing contexts, this study aims to make a case in point as it draws its knowledge and expertise from a variety of perspectives and shared common grounds within a partnership in the European Union.

The compilation of effective practices

In this study we have made the choice of presenting some key CPD practices that have been developed over the years and have proven their relevance and effectiveness. This does not mean that we have had only successes. All these activities and programmes are the results of long processes, still ongoing, that were punctuated with many trials and progressive improvements.

The place of research

This study does not intend to be a research work. It is neither a state of the art of CPD in Europe, nor an evaluation report. Its aim is to provide readers with a set of instruments on how reflective practice within CPD was developed. These introduced instruments do rely on qualitative evaluations, surveys and iterative processes of observation. Thus, this report gives first-hand elements about the practical experience of 5 national networks that have been developing STEM CPD activities for many years in their respective countries and contexts.

While some readers may regret the lack of scientific evidence of the impact of CPD on teachers and students, we assume the choice of witnessing about our experience and our conviction that our activities effectively answer the needs of teachers, as testified by all our qualitative evaluation findings. Besides this, numerous activities presented in the course of this document have scientific evidence supporting their impacts as they are conducted as parts of research projects.

References:

Costa, A.L., Kallick, B. (1993). *Through the Lens of a Critical Friend. Educational Leadership*. 51(2): 49–51.

Dunne, Faith & Honts, Frank. (1998). *That Group Really Makes Me Think*! *Critical Friends Groups* and the *Development* of *Reflective Practitioners*, Paper presented at the annual meeting of the American Educational Research Association, San Diego, CA..

Mayring, P. (2014). *Qualitative content analysis: theoretical foundation, basic procedures and software solution*- Klagenfurt. URN: http://nbn-resolving.de/urn:nbn:de:0168-ssoar-395173

2

The description of the main features of the 5 systems

AUSTRIA

IMST/NEP

Within the LINKS project, the two institutions IMST ("Innovations Make Schools Top") and NEP ("NaturErlebnisPark Science Education Centre") represent Austria. These two are characteristic for the complex and dynamic Austrian STEAM-Learning community network as they are two examples for the several national and regional networks for science education and science communication. In Austria, STEAM networks connect themselves loosely through independent organisations with the main purpose of enhancing network thinking as well as network activities. Usually, single institutions are involved in several of these networks at the same time while engaging in different cooperation programmes. These networks usually do not form a hierarchic relationship with each other; engagement and participation are based on the respective institution's own volition. Often, participation takes place during a certain time-period due to common projects.

In this sense, IMST contributes to the LINKS partnership with perspectives of a nation-wide network structure, NEP adds its experiences of what it is like to work as an independent organization that engages in different STEAM networks. IMST and NEP often collaborate with each other but neither is part of the other.

IMST – Alpen-Adria_University Klagenfurt[1]

Main features

IMST is a nation-wide support system and network to provide quality based innovations in STEM and German education. For this purpose, teachers and teacher educators implement innovative school projects and exchange their experiences through networks. IMST not only aims at affecting the individual instruction, but also the school development and the structures of the educational system itself. Colleges of teacher education and universities as well as schools (see e.g., Krainer & Zehetmeier, 2013).

[1] The following description is a condensed version of Yves Bernard's "Description of STEM Knowledge Networks in Europe" (*http://www.flanders.be/en/publications/detail/description-of-stem-knowledge-networks-in-europe*, *Download 14.11.2016*). We recommend reading the longer version.

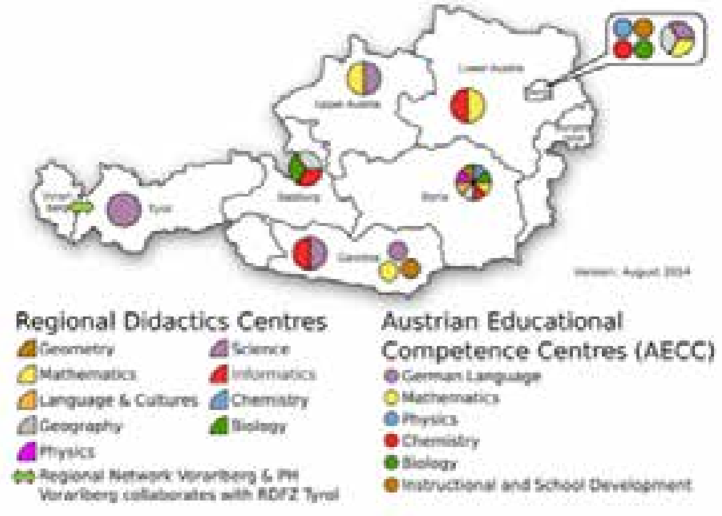


Fig. 4: IMST activities within Austria.

The initiative was taken in 1998 by the Alpen-Adria-University Klagenfurt to set up STEM as a cooperative structure between schools, school administration, universities/teacher training colleges and businesses. From the beginning, the initiative received support from one or two ministries. Initially, the initiative was limited to secondary education. However, gradually, kindergarten and primary education (and the professional development of their teachers) and pre-service teacher training were involved. The IMST initiative is coordinated by the Institut für Unterrichts und Schulentwicklung/IUS (Institute of Instructional and School Development) at the Alpen-Adria-University Klagenfurt.

The activities of IMST target teachers at all levels of education, schools and members of the school management teams, pupils, prospective teachers who are also involved in IMST initiatives, universities and teacher training colleges, regional education leaders, businesses and civil organisations, NGOs, research institutes and science centres, actors in informal and non-formal education and other education projects at national, European and international level.

The IMST headquarters are based at Klagenfurt University.

Objectives and activities

The overall goal of IMST is to contribute to establish a culture of innovative quality development to foster the STEM education at Austrian schools. This means to improve instruction in Mathematics, Science, IT, German and related subjects, to raise the attractiveness of STEM fields of study through promoting cross-curricular initiatives and school development and through the professional development of teachers.

IMST includes three strands:

The thematic programmes focuses on CBL and IBL to stimulate innovative projects in STEM. Each programme supports about 20 school projects a year, which were selected by an annual call (application process: application, reviewing, jury). After the projects were granted, the teachers are supported by the TP-Teams. The support is focused on accompanying teachers and school teams in their working process to enable good practice of the projects initiated by the teachers themselves.

The IMST Network-Programme supports regional networks in all nine Austrian provinces, and three thematic networks which operate at national level. Within the IMST thematic programmes, teachers put into practice innovative instructional projects and receive support in terms of content, organisation and finance bottom-up. The goals of the networks are threefold: Raising the attractiveness and quality of lessons in mathematics, biology and ecology, chemistry, physics, information technology, geography, descriptive geometry and related subjects, as well as promoting cross-curriculum initiatives and school development in grammar, vocational and secondary modern schools, primary schools and kindergarten, Professional development of teachers while involving as many schools as possible. The IMST Gender_Diversity Network supports the development of gender and diversity sensitivity in the quality of teaching. Teachers who gained these competences make better use of potentials and resources of their students and are enabled to better understand individualities.

Thus, gender mainstreaming and gender sensitivity are principles that aim at broadening educational opportunities, life plans and opportunities for all individuals. The network itself offers workshops, teaching materials, counselling and networking activities.

The main results so far

Since its establishment, the IMST network has successfully helped to establish a systemic approach within educational systems (see the vast list of publications the impact of this initiative). It sees itself as a learning community and thus is very open to further development in a changing educational landscape.

NaturErlebnisPark Science Education Center

Main features

NEP is an independent association, partly financed by the City of Graz. The institution is involved in several networks and acts as a long-term partner of the IMST network.

NaturErlebnisPark–Science Education Center has longstanding experience in the fields of development and research of educational settings for science education. The institution acts as a place for out-of-school learning. It offers a broad range of didactic activities to support science teaching at all levels of education from kindergarten up to secondary school as well as for out-of-school groups. The institution is part of the National Science Center Network and focusses on the cooperation between formal and informal learning as well as the training of explainers and teachers.

Objectives and activities

In our work, we focus on the personality building function and the social importance of science education and science communication. In a world shaped by science and technology, scientific literacy is an essential precondition for reasoned decisions and for participation in social discourse. We consider science education as a synthesis of imparting ways of thinking and acting, conceptual knowledge, values and attitudes as well as basic competencies. Scientific methodologies represent a prototype of an efficient, rationality-based problem solving strategy and contribute to face social relevant challenges in a reflected way.

STEM-CPD is organised in different ways:

- CPD activities for pre-service teachers are embedded in the regular curriculum of teacher training at the University College of Teacher Education Styria (Primary school and lower secondary school teachers) and the Karl Franzens University Graz (Grammar school teachers)
- CPD for in-service teachers of all educational levels is organised within the framework of the advanced training programme of the University College of Teacher Education Styria or the STEM professionalisation activities of the Austrian Science Centre Network
- Long-term CPD activities usually are included in special programmes founded by the Austrian Government.

Generally, the CPD activities are (a series of) face-to face workshops, preferably combined with an action research process of self-assessment focusing on pedagogical contents like Inquiry based learning as a structured process of gaining knowledge, problem based learning, Puppet Science, scientific competencies, development of interest, contextual learning, dealing with diversity and participatory research with children.

The scientific contents refer to the curricula and to the local context and cover the fields of biology, chemistry, physics, geography and technics, often provided in an interdisciplinary synopsis.

The main results so far

NaturErlebnisPark Science Education Center offers five workshops per semester, each for 25 participants. Long-term CPD projects last one or two years and are available for 6 schools.

FINLAND

LUMA is an abbreviation standing for natural sciences (LUonnontieteet) and mathematics (MAtematiikka), and generally it is translated as STEM. LUMA Centre Finland is an umbrella organization for LUMA Centres in Finnish universities and university campuses. Currently, there are LUMA Centres in all 13 Finnish scientific and technological universities as seen in Figure 1. The network is led by the national board of LUMA Centre Finland which has representatives from all member universities. Each LUMA Centre has various numbers of employees (nation-wide: approximately 90) who are responsible for the coordination of activities, conducting research and developing materials, etc.

Fig.1. Geographical locations of LUMA Centres in Finland.

The funding for the network comes mostly from the Ministry of Education and Culture and member universities with additional funding coming from other sources, such as companies, trusts, and the European Union (Erasmus+). With respect to the partners, LUMA Centre Finland works in cooperation with the departments of science and education in universities, schools and teachers, pupils of various ages, municipalities and companies.

Regarding activities of the LUMA Finland network, there is a national binding strategy that guides the activities implemented in the centres. However, this document affords an adequate amount of freedom so that all centres can have their own focuses.

The most important activities are related to collaboration with schools and other learning communities, formally, non-formally, and informally, at various levels. These activities include but are not limited to organising annual science fair contests (StarT festival) for local schools, developing and distributing new materials for schools in cooperation with teachers, organising school visits for LUMA Centres and their science classrooms, educating teachers, and lending equipment for schools. Another important form of activity is conducting research related to the themes introduced above; most of the employees in LUMA projects are PhD students or post-doctorate with a teacher educational background. LUMA Centre Finland also collaborates internationally with various quarters. Besides this LINKS project, there are also mutual agreements with other countries, such as China.

Annually, LUMA activities reach approximately 4000 teachers, thousands of pupils and students, and some thousands of other people, such as collaborators, parents, etc. People of LUMA Centre Finland publish approximately 40 articles each year in both international and national journals. Besides, there are some PhD dissertations and numerous bachelor's and master's theses done each year under LUMA activities.

FRANCE

The national network of the *Maisons pour la science au service des professeurs* is a large scale multi-stakeholders experiment for the professional development of teachers in science.

Main features

The network was launched in 2012, for an initial duration of 7 years.

9 houses have been created within regional science universities. They are governed in partnership with the *Rectorats (regional boards of the Ministry of Education) and the Foundation La main à la pâte.* Besides, the Foundation hosts the National Centre of the network.

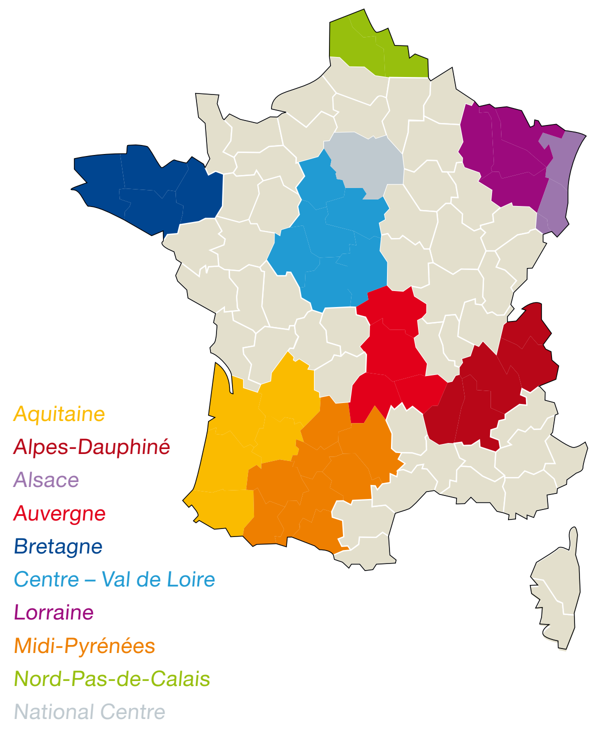


Fig.3: Geographical locations of the Houses for science in France.

While the regional Houses target mainly teachers – from primary and lower secondary levels, the National Centre's focus is on teacher educators and the production of resources. Moreover the National Centre acts as the coordinator, ensuring the respect of the general frame, the quality of the activities and the building –and possibly scaling up, of the network on the basis of the exchange of best practices and experience (capitalisation).

At local level, the network has developed the inclusion of pre-existing structures, known as *La main à la pâte* pilot centres that are now, in regions where a House has been settled, associated in the regional network as well as the new satellite centres.

The network is funded mainly by the *Programme Investissements d'Avenir* and by the hosting universities, with some additional support from the employers and the Ministry of national education. 50 full-time equivalent staff are mobilised as well as a budget of 26 M€ corresponding to an anticipated average cost of 685 € per beneficiary.

Objectives and activities

The mission of this network articulated from the national to the local level, is **to provide large-scale professional development** in the 9 targeted regions, with an objective of accessibility across the territory.

The network also aims **at developing in-depth professional development activities** in the form of 'paths' consisting of 80 hours of professional development, some of them are recognised by an official certification. These paths include both face-to-face sessions and distance-learning activities (blended professional development).

The major innovation of the network relies on the **close involvement of the scientific community** in professional development activities for teachers and their educators. The network has both capitalised on the existing ASTEP programme (involving scientists and scientific students in support activities provided to primary teachers), and developed new forms of cooperation. Researchers, engineers, technicians, coming from the university and other public research institutions or the industry, co-create and co-lead professional development actions, promoting a living science that encompasses digital sciences, cognitive sciences, engineering sciences… as well as a deeper comprehension of the nature of science, the skills and the openness to other disciplines required, especially when addressing complex issues such as sustainable development.

The main results so far

- 9 Houses and their 21 satellite centres covering their regions, plus 1 national centre
- 1,500 face-to-face PD sessions, all coupled with a collaborative platform and monitored through pre and post questionnaires, for the benefit of 30,000 teachers and educators
- 3,000 students involved in scientific support for the benefit of primary teachers and their classes
- 50% of scientists associated as contributors and trainers in the professional development sessions
- 2 MOOCs followed by 3,000 teachers
- Resources available on the Foundation website visited by 350,000 users per month

ITALY

The ANISN (Associazione Nazionale Insegnanti di Scienze Naturali) CPD network consists of 10 IBSE centres. It represents the evolution of the SID programme, which was triggered by the experience developed by ANISN in the European project Fibonacci. The continuous cooperation since 2009 with the Foundation *La main à la pâte* as well as with other European reference centres for CPD on IBSE and partnership in five EU projects has been pivotal for the development of the network and its systemic strategies. The cooperation with the Accademia dei Lincei in the framework of the SID programme, has represented a fruitful synergic enrichment and has empowered the scaling up of the network.

ANISN is a non-profit Italian Association devoted to improve CPD of Science teachers since forty years with thousands members organised in 26 local sections (www.anisn.it). It is recognized by the Ministry of Education as external body to hold CPD courses. ANISN mission and commitment in many activities, has represented the breeding ground in which the establishment and development of the systemic network of IBSE centers has been rooted and fostered. The key contribution of the international cooperation combined with the adoption of systemic strategies and the improvement of effective networking at various level, has allowed to build the sufficient architecture to sustain the processes, but the value of the human interface, persons who have assisted and assist others in the adoption and implementation of plans for change, has represented and represents the necessary condition for the positive results achieved so far.

To date the National network involves 10 Italian regions where centres for CPD courses on IBSE connected to local ANISN sections have been created progressively over ten years. The centres, hosted mainly at universities or (science) museums, share the same governance model (1 or 2 responsible; 4 – 8 trainers; a panel of scientific referees) and strategies to a long lasting involvement of local schools/teachers networks as well as the local scientific community involved in joint working groups, in co-organising professional development courses or in holding seminars on cutting edge scientific topics. The different centres have different dimensions dependent upon the time of their foundation and the contribution of synergic activities developed in the framework of European projects.

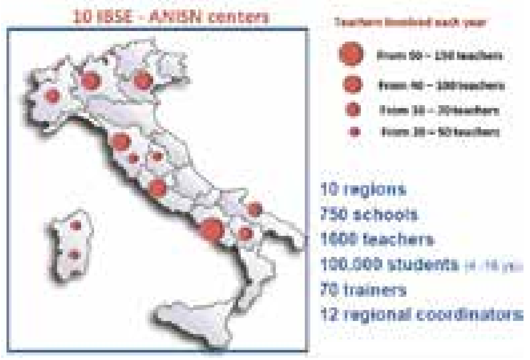


Fig.2: Geographical locations of ANISN Centres in Italy.

All the centres organise long term, in presence, periodic and multilevel training courses (novice, advanced and expert teachers; trainers) to improve the adoption of inquiry based teaching and learning at school. The courses follow a common architecture and mostly adopt the same resources, even if each centre is, obviously, a rich hotbed of modified or new resources which are shared among the centres feeding the availability of a growing amount of resources at National level. Trainees receive free of charge theoretical and experimental materials (kit boxes) and support (also in presence for novice teachers) of experienced teachers or trainers during the implementation with students at school. The target teachers belong mainly to primary and lower secondary schools, within the different centres, there is a variable ratio of teachers of different school levels.

Over the years, an average of 80% of attending teachers have followed the CPD courses for at least three years, thus improving consistently their expertise in IBSE. A cohort of typically holds different tasks in their school or at local centre or at National level. Systemic actions are guaranteed not only by the existence of National governance bodies, but also by different strategies which act as connections' strings on the common structural and functional architecture, such as: an annual agreement of a shared updated guidelines (with roles, responsibilities, general actions and models of multilevel training courses) signed by all those locally responsible; National meetings (or training courses) in person and at distance for advanced teachers or trainers; cooperation among members of different centres as working groups to develop new resources or to contribute in European projects; sharing of new resources in local courses by National trainers.

The lack of a unique partnership able to sustain most of the financial needs of the network of IBSE centres has forced, along the years, to a local and national multisource funding partnerships with scientific institutions, foundations, local educational authorities. Funding at National level to assure financial sustainability for system actions and to partially contribute to local actions, comes from Ministry of Education thanks to a project recently approved (i.e. School for Inquiry) and from a Foundation. In the last two years, some CPD courses have introduced fees, trainees pay these from their personal bonus (500 euro) given by Ministry of Education to all the Italian teachers to improve their PD. Funding from European projects are vital to support economically the network and to promote cross-fertilization within and among the centres as well as with other European CPD institutions. Schools contribute to the dissemination process and indirectly also to the financial sustainability of the centres, through their participation to the European PON (Piano Operativo Nazionale) for Italian regions, these funding options allow the organisation of join training courses (and events) at school level with the support of trainers and teachers of the local centre.

The success and impact of the network is sustained by systemic, shared strategies fostered by cross - connected actions at international, national and local level. External and internal evaluation supports the main evidences with data. Key elements are at the core of the impact and effectiveness of the ANISN CPD network of IBSE centres: a) the bottom-up approach to the organisation of professional development courses; b) the clear progress in the professional development from beginners to advanced; c) the participation of ANISN in European projects, which resulted in capitalization and cross-fertilization; d) the strong link with schools and school development projects; e) the commitment of dozens of volunteers; f) the permanent evaluation by teachers who took a professional development course, as well as their students.

UNITED-KINGDOM

STEM Learning

The **National STEM Learning Network** is the largest provider of STEM education and STEM careers support to schools, colleges and other groups working with young people across the UK. Supported by a partnership of Government, learned bodies, charitable trusts, employers and STEM professional bodies, the Network is dedicated to raising young people's engagement and achievement in STEM subjects, and increasing the numbers progressing in STEM studies and into STEM-related careers post-16.

STEM Learning enables teachers, technicians and others working with young people to engage with STEM-subject specific, career-long continuous professional development (CPD). The Network provides free online resources for STEM teaching and learning, based on the national curriculum. In addition, STEM Learning supports the STEM Ambassadors programme, STEM Clubs and a wide range of other STEM enrichment activities with proven impact on outcomes for young people. Working with employers of all sizes who wish to engage in STEM education, STEM Learning helps them maximize the impact of their investment on young people, teachers, schools and local communities.

The Network comprises:

- the **National STEM Learning Centre** at York, with state-of-the-art facilities for intensive teacher CPD and an extensive library and repository of resources;
- the www.stem.org.uk **website** containing over 11,000 quality assured resources;
- a network of forty five **Science Learning Partnerships** in England offering local access to subject-specific support;
- **our partners in Scotland, Wales and Northern Ireland**;
- nineteen **STEM Ambassador Hubs** across the UK linking individuals and STEM employers with schools, colleges, youth and community groups supporting young people in STEM.

The Network reaches directly into every UK secondary school and FE college, and over 80% of primary schools. Three thousand educators benefit from residential CPD or other activities at the National STEM Learning Centre each year, with another 20,000 engaging with local, high quality STEM-specific CPD. More than 30,000 STEM Ambassador volunteers, representing around 2,500 employers, take part in over 50,000 activities with schools, colleges and other young people's groups annually.

The STEM Learning Network operates a wide range of activities in STEM education. Their major programmes cover CPD, resources, STEM enrichment and STEM inspiration, and include:

Project ENTHUSE - providing opportunities and bursaries for teachers and technicians, schools and colleges to benefit STEM subject-specific CPD, through:

- transformational residential CPD at the National STEM Learning Centre in York
- bespoke support for schools and groups of schools
- online CPD
- STEM Insight teacher placements with employers and universities
- local support in Scotland, Wales and Northern Ireland

Science Learning Partnerships – a network of school-based organisations in England which are led by practicing teachers and deliver locally accessible CPD for STEM subjects- for all educational phases (early years to post-16).

HEaTED – providing CPD, networking and professional support to those working as technicians across FE and HE, including in STEM.

The National STEM Learning Centre – an inspirational venue in York that houses the UK's largest repository of resources for STEM education, state-of-the-art facilities for STEM-specific CPD, including residential experiences.

Curriculum Resources - free of charge access to over 11,000 collated and curated curriculum resources from early years to post-16, accessible through the Network's website www.stem.org.uk,

STEM Ambassadors – linking volunteers from a wide range of STEM backgrounds and disciplines with schools, colleges and informal educators who work with young people. STEM volunteers receive training and support to help them deliver effective and impactful activities by contextualising STEM teaching, raising aspirations and challenging stereotypes.

STEM Clubs network – encouraging schools and colleges to support vibrant STEM Clubs alongside other extra-curricular activities; supporting STEM learning, raising aspirations and encouraging practical skills.

ESERO-UK – using Space as a context to raise young people's achievement in STEM, including access to Space Ambassadors, resources, teacher CPD and events.

In addition to improving the quality of STEM teaching and learning, the Network supports high quality careers education, encourages diversity, social mobility and equality in terms of access to good STEM education. The other cross-cutting themes that are embedded in many of their programmes are:

- Building capacity, capability and communities of practice
- Helping employers and schools to develop long lasting relationships
- Recognising and encouraging teachers' and technicians' career-long STEM-specific professional learning.

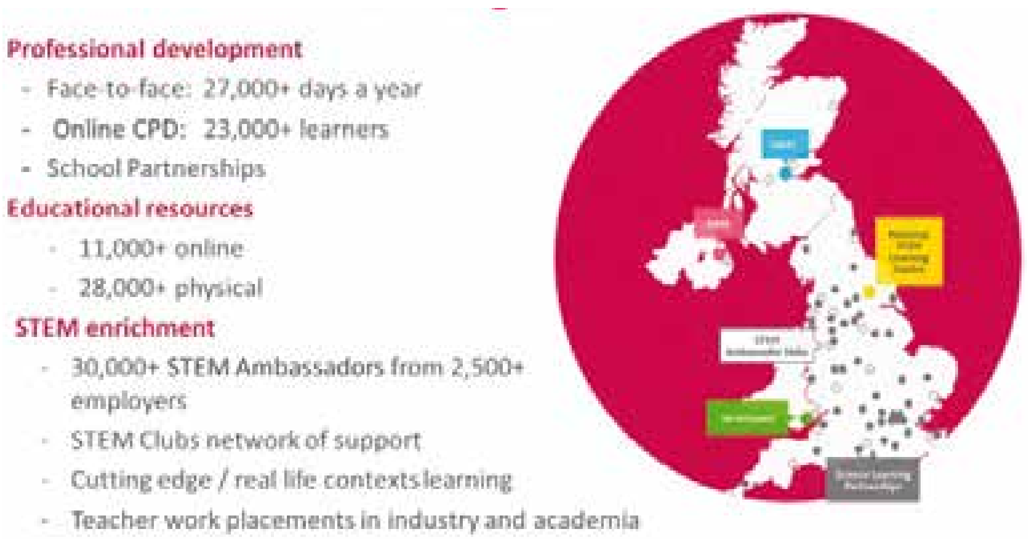
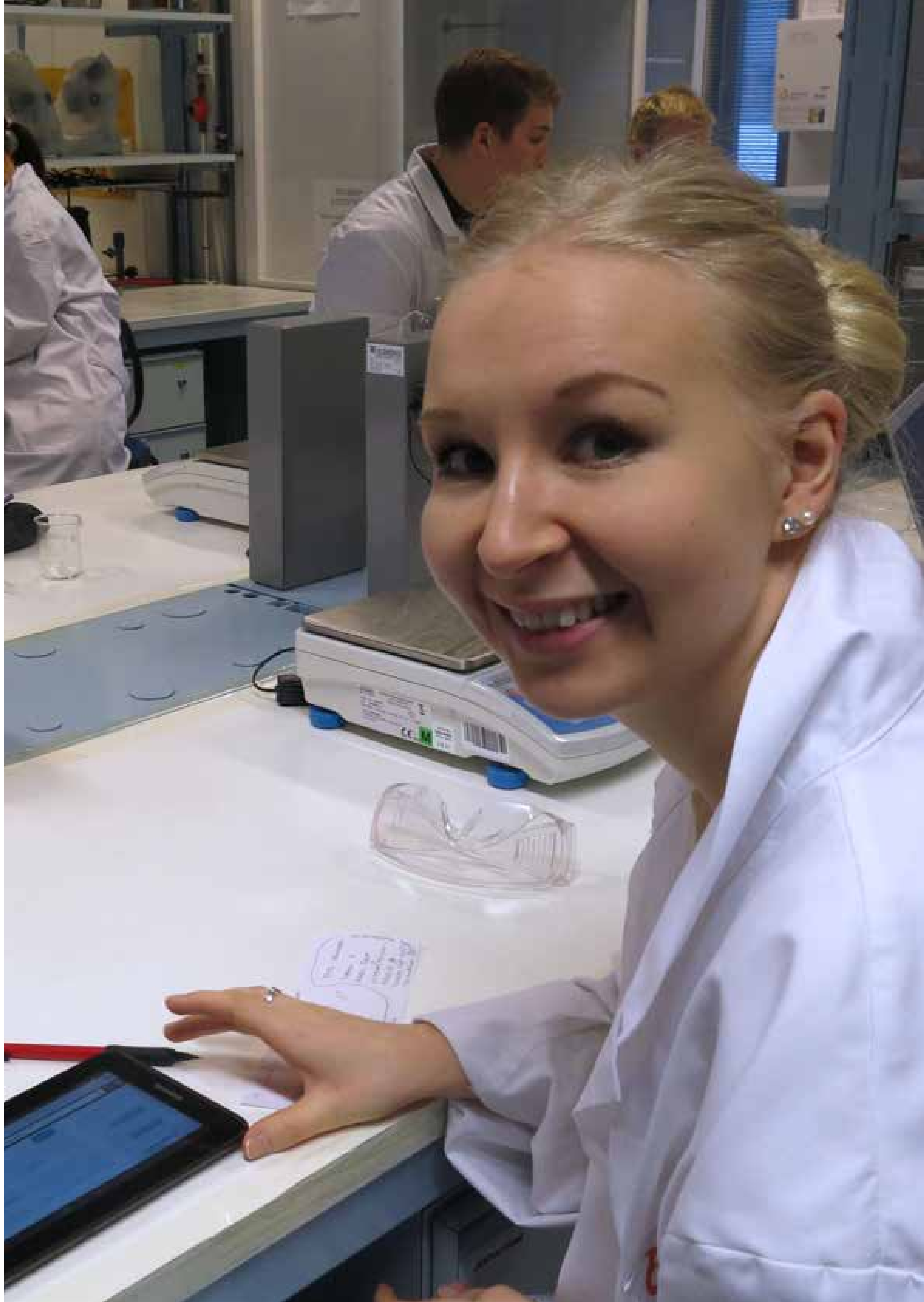


Fig.5: the national STEM Learning Network in UK.



3

Main levers for effective and impactful professional development

After the field visits and exchanges between partners some key issues have been identified as common to all partners. Not all are developed with the same extent in the five countries, some are addressed in a deeper or more innovative way, but all together they draw the picture of the main characteristics developed by partners to address the issue of quality CPD.

3.1 CPD core contents

The content of the activities offered to teachers and educators is a major issue in the review of continuing professional development. This content concerns both the field of knowledge - science in this case - and the teaching methods involved in the transmission of scientific knowledge.

The integration of both subject content knowledge (SCK) and pedagogical content knowledge (PCK) in the same CPD programme is beneficial to the teachers throughout their career, especially in countries where it is difficult to access CPD.

This integration takes different forms across the LINKS countries and partners involved in science CPD design and delivery.

However, the partners share the vision that this integration is more effective in a context where cutting-edge scientific content is addressed by putting teachers in the situation of adult learners. This approach allows teachers to have a learning experience at their level and to gain a better understanding of the difficulties that learners - including their students - may encounter when they face an unknown situation.

Hence the choice of **cutting-edge science** to renew SCK and of **Inquiry-Based Science Education (IBSE)** as an effective approach for the enhancement of PCK, especially when complemented with recent findings in the science of learning and the considera-tion for diversity issues.

Besides these two common pillars, LINKS partners also develop CPD innovations to address two major trends in STEM education: the attention to the **Nature of Science (NoS) and the development of interdisciplinarity**, both in line with the combination of cutting-edge science and IBSE.

3.1.1 Subject Content Knowledge: the choice of cutting-edge science

As time passes after their initial training, teachers risk seeing their knowledge become increasingly alien to the science that is currently being done in research laboratories and business research and development departments. Keeping abreast of current research topics is an ongoing concern for teachers. Indeed, this knowledge allows them to inspire their students with enthusiasm for a science in touch with current issues. Cutting-edge science CPD also promotes a better understanding by the teacher of the nature of science, and highlights the importance of interdisciplinarity in addressing science topics. Even when the topics taught have long been scientifically well established, a teacher familiar with current research can draw connections between the topics taught and today's research issues, giving depth to his or her teaching and allowing students to realise that there are still many scientific questions to explore.

Yet, there are few opportunities for teachers to maintain the link with advanced science: they do so through reading, but this approach, although crucial, does not replace direct contact with science teams in their workplace. LINKS partners offer professional development sessions during which participating teachers focus on cutting-edge science topics, and can be guided by scientists who work on these topics on a daily basis: researchers, engineers or technicians, from both the academic and business worlds. The commitment of an expert at their side underlines the importance of their teaching mission, and values their work.

References:

Baker, Y. *Secrets to science CPD success.* National Science Learning Centre, 2015.

Darling-Hammond, L., Hyler, M. E., Gardner, M. (2017). *Effective Teacher Professional Development Does Content-Focused Teacher Professional Development Work?* American Institutes for Research.

Higgins, S., Cordingley, P., Greany, T., Coe, R. (2015). *Developing Great Teaching: Lessons from the internatio-nal reviews into effective professional development*. University of Durham; Teacher Development Trust.

NSLC (National Science Learning Centre) (2015). *10 Years of Impact on Teachers, Pupils and Schools: Lessons in excellent science education.*

Timperley H. et al. (2007). *Best evidence synthesis on teacher professional learning and development. Wellington, New Zealand: Ministry of Education*.

In Finland, “Update your science knowledge” education days

One way to familiarise science teachers with cutting-edge science is to organise “Update your science knowledge” education days for teachers in cooperation with local universities. LUMA Centre from the University of Eastern Finland has planned these in cooperation with the Faculty of Science and Forestry by involving scientists with highly interesting research topics from all the departments of the faculty. These days consist of succinct informative presentations, guided tours in department facilities, and workshops with hands-on experiments.

Day 1 addresses the subjects of biology, forestry, and environmental sciences. The cutting-edge science themes introduced are (i) participatory science in the study of endangered Saimaa ringed seals in Finland, (ii) the future, diversity, sustaina-bility, and use of Finnish forests and (iii) radiation research related to environmental healthiness. Day 2 consists of an introduction to cutting-edge themes related to physics, mathematics, chemistry, and computer science. The topics introduced during the day are (i) augmented reality in a physics laboratory, (ii) new trends in mathematics research (iii) the control of emissions in energy production, (iv) machine learning and speech recognition.

These education days have been particularly successful with secondary teachers, and the feedback from the field has been very positive. The departments of the University were very strongly committed to this project, which brought researchers and students closer from each other.

In UK, the Research Council Cutting Edge Science programme

The Research Council Cutting Edge Science programme (RCUK) aims to enable teachers to inspire their students particularly age 14-19 through learning about advances in scientific research, improving their understanding of how science works and engage with active and inspiring activities. With teachers' time taken up with curriculum demands, marking and other pressures it is difficult for them to research current scientific ideas and theories, instead relying on ‘old’ science and its applications, so they continue using old ways of teaching science which often lack inspiration and relevance.

STEM Learning's educational experts work with university and industry-based researchers to develop Cutting Edge Science resources and CPD opportunities for teachers in secondary and post-secondary education, which help school educators relate their teaching to 21st Century science. Resources and CPD created through this collaborative work cover a wide range of topics, ranging from Astrophysics to Bioinformatics and Genomics. Importantly, the involvement of CPD experts, who have good understanding of school education, allows tailoring the findings from STEM research to teaching of the national curriculum, making them relevant to teachers and easy to implement. The input of researchers could vary from sharing their subject expertise and ‘authentic’ contexts with CPD developers to participating in CPD delivery or leading/hosting CPD sessions.

For example, the CPD course on Astrophysics for those teaching secondary and A-level physics is a one-day course delivered via a partnership between a teacher-presenter and lecturers. This is a very popular course which has run multiple times during the last three years, It combines astrophy-sics lectures by academics with demonstration material and signposting to online resources that teachers can take away to use in their classrooms. The topics covered include extrasolar planets, how elements are created within stars, and the big bang. It makes close links to the secondary curriculum, while maintaining a focus on cutting edge science and techniques. The course is run in a large laboratory, where teachers listen to presentations at one end, and can take part in demonstrations with laboratory equipment at the other. Teachers leave the course with apparatus to use back in their own classrooms so that they can recreate the experiments and activities, and are sent an electronic pack of the lectures and further resources once they are back in school.

There is also a suite of resources for teachers to access on a dedicated collection page which has links to resources, including videos, papers and activities on such diverse topics as:

- Quantum Key Distribution – Encryption from the Enigma machine to WhatsApp protected messages.
- Controlling Plant Cell Division to Enhance Biofuel Production

In France, an example of a professional development action taking place in a research centre: CERN

Training in laboratories and in companies allows participants to visit specific facilities, to better understand how they are used and also to update their knowledge in relation to cutting-edge science.

For example, a professional development session, on the topic of matter, involves 3 days of face-to-face training at CERN (European Organisation for Nuclear Research). During a master class, a scientist working on ATLAS particle detector suggests to the participants to analyse traces left by the particles detected at the LHC (Large Hadron Collider) using one of the research centre's data analysis software. This session allows teachers to understand how to interpret traces and released energies after collision of two protons. Thus, by selecting the detected signals, the participants are put in the situation of a researcher who has to identify the particles created in the LHC from data

analysis. Being on a site dedicated to research in particle physics makes it possible to work on some fundamental aspect of the scientific process: the selection and interpretation of data to understand an experimental phenomenon inaccessible to our senses.

3.1.2 Pedagogical Content Knowledge: IBSE as a common framework expanded by innovative developments

Inquiry-based science education (IBSE): a major focus for all LINKS partners

IBSE is the main approach to science learning promoted by all LINKS partners, though not the sole one they refer to.

IBSE focuses on students' interests and drives them towards active learning by allowing them to handle their own inquiries (Driver, M., Braund, M., 2005).

It appears to be an effective way for students to develop their conceptual understanding of scientific phenomena (Minner D. D., Levy, A. J., & Century, J., 2010), giving them the opportunity to think and act in a similar way to scientists. As a result, students develop the ability to conduct inquiry and understand scientific research (NRC, 1996). This means that inquiry is both a 'mean' and an 'end' (Abd-El-Khalick et al., 2004), and is a teachable subject in itself (Bybee, 2000).

Inquiry-based learning outcomes engage teachers not only in providing students with hands-on activities, but also in facilitating mental activities based on critical and logical reasoning through cooperative work and discussion (Harlen & Allende, 2006). Furthermore, embracing IBSE asks teachers to explicitly highlight key aspects of the Nature of Science (NoS) through thoughtful discussion with students about the practice of science (Lederman, 2006).

There is no single model of inquiry based teaching, but it can be implemented in various ways that differ in the degree of teacher's guidance and the degree of learners' responsibility (Bianchi & Bell 2008). It is desirable that little by little, the teachers lead the students to design their investigations by themselves, to explore their own investigable questions, with a high level of cognitive demands. In fact, IBSE can positively affect learning outcomes of students through facilitating open inquiries (Berg, C. A. R., Bergendahl, V. C. B., Lundberg, B. K. S., & Tibell, L. A. E., 2003).

During the whole process, the teachers play the role of facilitator providing students with appropriate scaffolding through the learning pathway.

Precisely because IBSE is very diverse, the various European countries involved in LINKS have adopted a set of strategies and practices in order to develop IBSE skills among teachers.

In most cases, there are a variety of opportunities for teachers to approach IBSE, starting with their **initial training**, and continuing as part of **in-service training.** IBSE-related training courses typically provide both an opportunity to experience investigation as an adult and an analysis of examples of classroom investigation sessions. In particular, PD activities are designed to facilitate *'learning through inquiry'* rather than *'learning about inquiry'* (Harlen & Allende, 2006). In order to practice IBSE in a most effective way, **teachers are engaged in a first- hand investigation which helps them develop an active understanding of what inquiry means** (see examples from France and Italy). They are considered as adult learners and encouraged to deal with inquiry by interacting and collaborating with their colleagues. These activities often provide teachers with the opportunity to reflect on the nature of science.

To better drive teachers towards an effective IBSE approach, in-service trainings are developed; most of these training courses are held in cooperation with researchers and include meetings during which they share knowledge about possible methods to support students' questions and bounce back on them.

Indeed, a key point for a teacher to conduct effective IBSE seems to be the ability to identify investigable questions, among some students formulate spontaneously (see examples from Austria and Finland). For this reason, teachers are often invited to explore different possible ways to design an investigation for the classroom. A difficulty is to reach the right balance between individual interests and the common topic under study.

Innovative pedagogical content knowledge reinforce IBSE

Even if IBSE is the core approach developed by all partners, most of them have also been working with new research inputs in the recent years. Especially thanks to the development of cognitive sciences, opportunities for researchers with expertise in the science of learning are created, in order to adapt their findings to the classroom (see example from UK).

Another prominent addition to the IBSE framework that is strongly developed by some partners is the consideration for diversity issues in STEM education.

Teachers have a special function when it comes to socialisation processes within schools. They interact with students and can support classical/traditional or innovative gender performances. At the same time, they act as role models themselves. They construct gender through their transfer of knowledge via the chosen subjects and materials (keyword depiction of men and women in textbooks). The chosen methodology/didactics shapes the learning environment as well as the framework within which the personal scope of action might be enlarged or limited.

Research has shown that stereotypical addressing in teaching practices sets in motion a downward spiral of students' motivation to engage in STEM (Ertl et al., 2017). Demotivated students then form a negative view of themselves as learners and ascribe their lack of interest in STEM subjects to their supposed inadequacy to these subjects. For example, belonging to a particular gender or social class, students may ascribe themselves less talent or curiosity to a subject. Together with these external messages ("You have no talent"), messages from the inside ("Don't be curious, it is not for you") reinforce the demotivation cycle. For example, several studies for Austria show that the majority of girls in elementary school are already less akin to mathematics compared to their male classmates (Nagy, 2009). (see example from Austria)

References:

Abd-el-khalick, F., BouJaoude, S., Duschl, R., Lederman, N., G., Mamolok-Naaman, R., Hofstein, A., & Tuan, H. (2004). *Inquiry in science education: International perspectives.* Science Education. 88 (3), 397-419.

Bianchi, H., & Bell, R. (2008). *The many levels of inquiry.* Science and children. 46 (2), 26-29.

Bybee, R. W. (2000). Teaching Science as Inquiry. In Minstrell J., Van Zee H. (Eds), *Inquiring into Inquiry Learning and Teaching in Science* (pp. 20-46). Washington, DC: American Association for the Advancement of Science.

Ertl, B., Luttenberger, S. & Paechter, M. (2017).*The Impact of Gender Stereotypes on the Self-Concept of Female Students in STEM Subjects with an Under-Representation of Females*. Frontiers in Psychology. 8(703). doi:10.3389/fpsyg.2017.00703

Harlen, W., Allende, J. (2009). *Report of the Working Group on International Collaboration in the Evaluation of Inquiry-Based Science Education (IBSE) programs*. Santiago: FEBA, 2006.

Harlen, W., & Allende, J. *Report of the Working Group on Teacher Professional Development in Pre-Secondary IBSE*. Fundacion para Estudios Biomedicos Avanzados, Facultad de Medicina, University of Chile.

Lederman, N. G. (2006). Syntax of Nature of Science within Inquiry and Science instruction. In Flick, L.B,

Lederman, N.G. (Eds) *Scientific Inquiry and Nature of Science* (pp. 301-317). Netherlands: Springer.

Nagy, G. (2009). Forschungsprojekt „Geschlechteraspekte in der schulischen Leistungsbewertung" Teil I: Bericht. https://bildung.bmbwf.gv.at/schulen/unterricht/ba/vs_fb_t1_21126.pdf?61ecim [17.02.2018]

National Research Council. (1996). *The National Science Education Standards*. Washington, DC: National Academy Press.

In France, experiencing inquiry as an adult learner

In the *Houses for Science* network, teachers approach IBSE in different phases during the proposed training sessions. During a first phase, they live an investigation as adult learners, and analyse what they have experienced with a reflexive approach on the nature of investigation.

They are explicitly asked not to consider what could be done in class with students but to engage themselves in a scientific research involving their own skills and knowledge. The chosen situation and the ways of working respect the principles of IBSE and are basically identical to a classroom implementation. Obviously, the trainer does not give the answers; he or she guides the adult learners in their own approach and encourages them to deal with their research by interacting with their colleagues.

The second phase is dedicated to taking a step back and discussing the experience that has just been lived: what were the roles of the participants and the trainers, which inquiry path was followed by the participants? This analysis is used to develop a draft-definition of IBSE. To improve this definition, participants then review schematisations of IBSE. Finally, they complete their analysis by viewing class videos, with a focus on both the different stages of IBSE and the professional gestures of the teachers.

A technological challenge: "Small cars": Build a small vehicle that will roll as far as possible. It must carry on its own propulsion system.

Investigation phase: the participants, once they have observed the material they can use, draw/design a personal-prototype to answer the challenge (individual phase) and list precisely the material needed. Then, in groups, they exchange and argue on their ideas in order to design a group-prototype, taking into account ideas from all members of the group. Next, following their design, they build their prototype and test it. Most of the time, first prototypes work very poorly. Thus, the groups enter a phase of trial and error: they identify the problems and improve their prototype, changing one parameter at a time. This loop is repeated until the prototype is optimised. When the dedicated time is over, the groups, one by one, present their prototype, the mechanism they used for propulsion (e.g. deflation of a balloon or untwisting of an elastic band), the difficulties they had and the solutions they found. To close the technological challenge, the groups organise a race between prototypes to verify which prototype goes the furthest.

Of course, the scientific concepts at stake are clarified (force, energy, movement, friction, resistance, Newton law…).

Reflexive phase: the participants analyse the different moments they went through and try to build a general scheme of IBSE from the activity.

In Italy, involving teachers in a simulated real situation about global warming

The activity "Arctic and the Antarctic", which deals with the global warming effects, engages teachers in a simulated real situation. This activity is provided in CPD courses by different centres mainly because of the relevance of the topic addressed. Moreover the scientific knowledge concerning the global warming is often faced incorrectly by the media, causing misconceptions which drive the students toward wrong ideas, conclusions and explanations.

During the first phase of the training session a video on climate change is shown to the trainees; then a sequence of images related to weather events, with an important environmental impact, is given. An article on global warming and Arctic and Antarctic glacial melting is also provided. During this engaging phase teachers often formulate interesting investigable questions and the most significant ones, as for example: "What are the effects of ice melting in the Arctic and the Antarctic on sea levels?" are chosen as research question to be explored by trainees organized in small groups work.

Independent groups have to formulate their hypothesis to try to answer the selected question and have to design and carry out an investigation to test their predictions. For their investigation trainees can freely choose from a wide range of provided materials, including ones not suitable for modeling the two types of environments.

The analysis and the comparison among the teachers' investigations reveal common and diffuse misconceptions about the characteristics of the Arctic and the Antarctic environments and many errors in modeling them, which affect the possibility of testing the hypothesis.

Such approach allows teachers to become aware of the critical intrinsic aspects of this issue and drives them to deepen many key contents of different subjects. At the same time, the "Arctic and Antarctic" training activity developed using low cost materials, easily allows teachers to implement it at school with their students being aware of possible common misconceptions.

In Finland, the 'Good question!' project

As a part of LUMA Finland Development Programme, a project "Good question!" was developed and implemented with in-service primary level teachers. In the project, eight teachers from three schools developed methods for question-based STEM education in cooperation with the researcher of the project. For example, one of the projects was related to water, and all the experiments were based on pupils' question: "How to clean water?" The project included meetings, sharing knowledge concerning possible methods to support and use pupils' questions, testing these methods in teachers' own schools, reflecting the use of the methods, and developing them furthermore. Those methods include for example the use of question-stems, pictures and experiments to help and inspire the students to formulate questions. Questions were used mostly in inquiry-based learning activities, in which the students` questions were modified and used as research questions. The topics included water, sustainable development, and electricity, to name but a view. Pupils' questions might challenge teachers but they can also provide fruitful chances for discussions, as the following examples show: "How to clean water?" and "Who is responsible for climate change?"

As a result, a practical question-based model for education was developed in co-operation with the teachers (https://hyvakysymys.wordpress.com/). In the methods developed, inquiry-based learning was emphasised significantly. Examples of the practices were also distributed with the aid of a shared blog. After the development phase, these pedagogical practices will be used in in-service teaching for a wider audience, also as web-courses.

In UK, the Science of Learning Project

The Science of Learning Project is a current example and collaboration between the Wellcome Trust, Professors of Neuroscience and Education and the ENTHUSE subject specialists at STEM Learning. The over-arching aim of the project is to provide opportunities for researchers with expertise in the science of learning and STEM subject experts with recent classroom experience to work together on adapting the findings from the most current research in this area to teaching and learning of STEM subjects in school. By translating these findings from neuroscience into relevant and practical advice for teachers, the project adds to a positive impact on young people in the classroom.

After holding two very productive workshops led by Professor Paul Howard- Jones, a Neuroscientist in Education at Bristol University and Professor Tim Jay of the University of Sheffield Hallam, STEM Learning educational experts developed a number of stand-alone teaching resources as well as a massive open online course Science of Learning which is focused on the key concepts of the research.

For example, one of these concepts which originally came from the field of psychology, is the idea of 'spaced learning', i.e. learning content multiple times with breaks in between. Although the benefits of spacing learning sessions compared with massing sessions together were known to psychologists for some time, they could not explain the phenomenon. Recent neuroimaging studies filled this evidence gap and gave clear guidance for the optimal application of this learning technique, including the ideal length of learning periods and the gaps between these. This and other core concepts in the science of learning together with the underlying evidence and guidance on how to apply these ideas on practice are embedded throughout existing and new CPD and resources provided by STEM Learning and shared with STEM teachers across all educational phases.

In Austria, raising the awareness of educators on gender and diversity issues: the Austrian initiative

In order to leave no student behind and to gain and keep the interest of all students in STEM subjects, the IMST gender_diversity network was founded in 2001. Its core approach is to work with educating the educators to spread knowledge about unequal access to STEM fields of study, about teaching practices that reinforce stereotypes and about the necessity to reflect the STEM subject teaching cultures in order to include all learners.

Therefore, we sensitise educators on teaching practices that above all point out the "otherness" of learners in the respective learning context. Be it because the learners have a different gender than the majority of the class or because they are perceived as "other" students due to their social status, language skills or physical conditions. In other words, we encourage teachers to reflect on how they interact with non-idealistic learners in their subject culture. What in their teaching practice relates on stereotypical assumptions on learners?

How can teachers now counteract "doing gender" and "doing difference" processes with their different effects on the skills, interests and self-concepts of children and adolescents? How can educators prevent a socialization-based deselection of STEM subjects? As a teacher, how can I address the lives of all my students by choosing my teaching materials? Perceiving and working with the "doing gender" as well as the "doing difference" in one's own actions and that of the pupils is the core effort of the IMST gender_diversity network.

Therefore, the IMST network offers the educators workshops in this field. The offer is voluntary. IMST regional network, as well as the scientific teams of the thematic programmes, are entitled to book tailored workshops. The IMST gender diversity network also cooperates with the ministry of education to ensure further education for federal teachers in STEM science didactics and gender and diversity approaches. E.g. in 2017 one three-day long federal seminar took place in Salzburg. A MOOC learning phase was included in the program. Additionally, the IMST gender_diversity network offers teaching guidelines and manuals on its website www.imst.ac.at/gdn.

3.1.3 Nature of Science

CPD activities focused on cross-cutting science and inquiry have been key to develop a more realistic vision of science -and societal challenges involving science- among teachers. However, a more developed understanding of science values and the scientific endeavour is required in order to foster responsible citizenship and critical thinking.

For centuries, science and science-based technologies have been shaping our material, intellectual and cultural environment in a transformative way. This process has been accelerating during the last decades, as information technologies have become widespread. Scientific topics such as climate change, vaccines, GMO now make the object of heated societal and political debates. A central aspect of responsible citizenship is represented by the capacity of identifying the conditions of validity, the relevance and the specificities of scientific knowledge, as well as the conditions of applicability of this form of knowledge to societal issues. For this, familiarity with scientific concepts and finding is not enough. What is required is a deeper, explicit understanding of the conditions of production, significance and limits of scientific knowledge in various disciplines. While we assist to alarming societal developments such as the increasing scepticism about science, the esoteric boom or the spread of fake news, it becomes necessary to draw the attention upon scientific values such as the will to laid ideas upon fact and to revise them in the light of new available evidence.

This is why a proper scientific culture should go beyond skills and knowledge related to science and cover the nature of science – including science values and scientific inquiry.

Starting from the 2000s, science educators have advocated teaching the nature of science through explicit, reflective instruction, aimed at increasing the awareness of students about main epistemological concepts, such as: the tentative nature of scientific knowledge, the fact that scientific knowledge is empirically-based and theory-laden, the role of creativity in science, the scientific method, the social-embeddedness of science.

It has more recently been pointed out that such "conventional" depictions of NOS are not sufficient for capturing authentic science, in particular because they leave behind some aspects of science as a social system embedded in specific institutions and in a cultural framework. In their reconceptualization of the scientific system, Erduran & Dagher claim for a broader view of science as a system that includes both cognitive-epistemic as well as social-institutional aspects: aims and values, knowledge, methods and methodological rules, practices, ethos, specific professional activities, systems of social certification and dissemination, the interaction with political structures, financial systems, social organizations and institutions. They advocate the position that interdisciplinary accounts of science ranging from philosophy to linguistics to economy have better chances of providing a more authentic view of science for STEM education than traditional accounts based on a positivistic view.

Nonetheless, the "conventional" view of science seems to make a good starting point - at least pragmatically – for teaching the nature of science and for CPD.

References:

Erduran, S. & DaGher, Z. (2014). *Reconceptualizing the nature of science for science education: Scientific knowledge, practices and other family categories.* Dordrecht: Springer.

Erduran, S. (2014). *Beyond Nature of Science: The Case for Reconceptualising Science for Science Education.* Science Education International Vol. 25, Issue 1, 2014, 933-111.

Kamporuakis, K. (2016). *The 'General Aspects' Conceptualisation as a Pragmatic and Effective means to Introducing Students to Nature of Science.* Journal of Research in science Teaching (Vol. 53, No. 5. 667 – 682).

Lederman, N. (2007). *Nature of science: Past, present, future.* In S. Abell & N. Lederman (Eds.), Handbook of Research on Science Education (pp. 831-879). Mahwah, NJ: Lawrence Erlbaum.

McComas, W.F. & Olson, J.K. (1998). The Nature of Science in International Science Education Standards Documents. In McComas (Ed.) *The Nature of Science* in Science Education: Rationales and Strategies (pp. 41-52). The Netherlands: Kluwer Academic Publishers.

Murphy, Smith, Varley & Razi. (2015). *Changing Practice: An Evaluation of the Impact of a Nature of Science Inquiry-Based Professional development programme on primary teachers*. Cogent Education.

In France, the project "Scientific thinking, Critical thinking" for primary and middle school

Critical thinking is a broad term hardly defined. Several educational approaches exist that favor critical thinking education as media education, cognitive debasing, logical argumentation, argumentative debate. While inclusive of all these aspects, the pedagogical activities developed by *La main à la pâte* make the case that science is a reservoir of cognitive tools with the potential to help overcome common false steps that hinder our reasoning and limit our capacity of gathering correct information. The project's activities guide students towards better first-hand information gathering: students learn to recognize the natural limits of intuitive observation and explanation; they identify strategies – commonly used in the framework of science – that help overcoming these limits. Teachers are instructed to explicitly draw the attention of students upon the fact that scientific "tools" can be imported in their personal cognitive toolbox so as to lead to deeper knowledge, more grounded judgments and better choices in their daily lives.

Each lesson is also the occasion to develop a better understanding of science as the human cultural answer to the problem of producing better knowledge starting from a rich but limited natural cognitive toolbox. In a typical activity aimed at primary school, students are confronted with the problem of deciding which, among several types of kitchen paper, is "the best". Students are helped by the teacher to put in place experiments of various kinds so as to test a feature of their choice and to compare the different papers on solid grounds. They reflect about the fact that the protocol they have put in place is a simplified version of protocols that are put in place by scientists in a variety of domains. While putting this kind of protocol in place is not necessarily practical in daily life, it helps understanding why scientific knowledge is more trustworthy than mere opinions: because it implies an effort towards objectivity, and dedicated strategies to achieve more objective views, that are not the common currency in daily life. A second group of activities is aimed at guiding students through second-hand information gathering: how to make a search on the web, how to evaluate sources of information and how to distinguish good and less good arguments, facts and opinions in the framework of a factual debate. Scientific contents and scientific tools are used as test-beds and aids. A final group of activities draws students' attention on how to use a rigorous methodology to solve new problems such as: inventing a new thermic container or… surviving in the desert with the help of some knowledge about dew-collecting insects. Activities thus cover five fundamental aspects of science: observation, explanation, evaluation, argumentation, problem-solving. Each aspect is treated separately for different ages, as the project is aimed at children spanning from 6 to 16 years old. Activities become progressively more disciplinary from primary to middle school so as to include content-knowledge that is sought for in the current curricula.

In Austria, Nature of Science as the basis of STEM education

The workshop "Collaborative, Creative and Discursive - Research and Competencies for the 21st Century" by ScienceCenterGraz at the University of Graz explicitly addresses a systemic and social understanding of "Nature of Science" as the basis of STEM education. Methodologically, a design-thinking process is used that combines scientific research and discursive steps to solve problems. In addition to technical and procedural aspects of science, questions of validation of research and development, adaptation to different user groups and the dependence of research on framework conditions and resources are discussed. The educational event is aimed at teachers of different school levels and teachers at the children's university.

3.1.4 Fostering interdisciplinarity in STEM education

During the past few decades or so, interdisciplinarity, multidisciplinarity, or integrative instruction has taken a firm foothold in national standards and curricula in various countries (e.g. Finnish National Board of Education, 2014). As a consequence, science teachers are facing new types of challenges as interdisciplinarity is often a rather new concept for them. Thus, some emphasis should be placed on providing in-service and pre-service teachers with CPD concerning functional and effective interdisciplinarity.

The most immediate motivation to introduce interdisciplinarity into teaching emerges from the world around us: the situations we face are never categorized the way subject matter is categorized at school. On the contrary, they fall into different fields of knowledge at the same time. Therefore, project-based or phenomenon-based teaching is naturally interdisciplinary, which makes it easier to combine the content addressed with learners' interest and needs (Czerniak, Weber Jr., Sandmann, & Ahern, 1999).

With respect to research related to interdisciplinarity in STEM education, numerous articles address the meaning of the concept, the benefits of interdisciplinarity, teachers' views, etc. (e.g. Wang, Moore, Roehrig, & Park, 2011). A literature review by Czerniak et al. (1999) suggests that interdisciplinary teaching awakens pupils' interest and enhances their learning outcome, and that teachers mostly have a positive attitude towards it.

However, there are some elements in interdisciplinarity that face well-argued criticism, such as constraints related to time, teachers' know-how, and collaboration with other teachers. Despite the criticism, it appears that the pros of interdisciplinarity top the cons, and thus it is essential to ensure that teachers have the necessary resources to implement interdisciplinarity in their professional practice.

A first way to engage in interdisciplinarity during CPD can be to start from a phenomenon or subject that clearly falls within **various fields of STEM.** The subject should be approachable from the perspective of various disciplines, preferably at the same time and without clear boundaries. This includes applying knowledge from various fields of knowledge, understanding the nature of science in general, and using various methods typical of different disciplines. In addition to the above, it is possible to explicitly address and experiment collaboration between teachers who are expert in different subjects, as this could be a concern for some teachers.

A second way is to involve *non-scientific disciplines too*. Within the LINKS partnership, we find excellent examples for phenomenon-based teaching settings that analyse complex every-day situations from different perspectives (e.g. ecologic, economic, social, ethic) and initiate discussions and consensus-finding processes.

In both cases, CPD offers should give teachers opportunities to address issues directly related to real life, in order to emphasize the usefulness of an interdisciplinary approach. These issues can be identified at various levels of complexity, from everyday life (see examples from Italy) to major challenges, for instance in relation with sustainable development (see examples from France).

References:

Czerniak, C. M., Weber, W. B., Sandmann, A., & Ahern, J. (1999). *A Literature Review of Science and Mathematics Integration*. School Science and Mathematics. 99: 421–430. doi:10.1111/j.1949-8594. tb17504.

Finnish National Board of Education (FNBE). (2014). *National Core Curriculum for Basic Education 2014*. Helsinki: Next Print Oy.

Wang, H-H., Moore, T. J., Roehrig, G. H., & Park, M. S. (2011). *STEM Integration: Teacher Perceptions and Practice. Journal of Pre-College Engineering Education Research*. 1: 1-13. http://docs.lib.purdue.edu/jpeer/vol1/iss2/2/

In Italy, two ways to address interdisciplinarity in connection with daily life

An investigation on bread: scientific interdisciplinarity

The activity "*investigating bread*" aims to capture the complexity of this very common food by integrating various scientific subjects. The learning path is designed in order to bring out, and use the way of knowing common to all these subjects and develop their awareness.

In the first phase of the training session, the teachers have to carefully observe different types of bread (with oil, with milk, stuffed, whole wheat, and so on), and then to identify some criteria to sort them appropriately. Many investigable questions arise such as: 'Why are there small or bigger empty spaces?' 'What are the energy values of the different kinds of bread?' Divided into groups, the teachers formulate hypothesis related to the question they have chosen within their group or the one that all the trainees have chosen. They make a list of factors to be tested, such as: the presence of yeast, of salt, of sugar, the handling time, the temperature, the type of flour (wheat, rice, oats, corn) and the type of yeast (brewer's yeast, mother yeast, chemical)… Teachers have to reflect on how to make a fair test changing one factor at a time, while keeping all other conditions the same, in addition they have to compare the data collected with the control-sample bread, produced according to a basic recipe. Finally, teachers identify the evidence from the data collected to answer the investigable question(s).

Making a map on bread can help to visualize the conceptual nodes related to the topic "*investigating bread*", as well as the different fields of knowledge involved. For example, biology is necessary to understand the leavening process, chemistry is needed for recognizing the produced gas, mathematics and physics together with biology are used for calculating the energy values of various types of bread.

From the discussion on the contributions given by the various subjects emerges the methodological aspects they share, such as the regularity and repeatability of their procedures and the use of evidence.

Education for sustainable development: from science to other disciplines

The example described below is an innovative IBSE-based "toolbox" on Education for Sustainable Development (ESD) topics for teachers and teacher educators. It was developed in the framework of the SUSTAIN project. ESD requires a complex and multidimensional approach, which includes environmental, economic and social aspects, and involves both scientific and non-scientific fields of knowledge. Here, we focus on a single example that is the analysis of the life cycle of an everyday object: the cup. The life cycle of this object is analysed starting from the present (the daily use of the object), going back in time (how this object was made and how it reached its place of use) and wondering about its future (what will it become at the end of its life?). Initially, teachers have to observe a collection of cups, focusing on the factors that guide individual choices. Among them they can include both measurable variables (capacity, weight, insulation, cost, material etc.) and subjective factors (colour, brand, decorations, etc.). Paying attention to the present of cups, teachers are asked to make predictions about some measurable proprieties: which cup keeps the drinks the hottest, which cup is the lightest, the most resistant and so on. Through investigations,

teachers gather evidence to test their predictions. Considering the “past” and the “future” of the life story of the cups, the attention is then focused on the materials used to make them and where those come from. In addition, the possibility of reusing or recycling the cups is analysed, considering also the economic and environmental costs. Comprehensive mind maps have been developed, as examples of useful tools to approach and develop interdisciplinary contents, emphasizing their complexity and interconnections.

With the cooperation of literature, geography, economics and history teachers, a “Seller of cups” role-play is run. It highlights the three interdependent economic, social and environmental pillars of ESD. Role-playing encourages reflection on individual choices and their consequences, with a view to promoting individual behaviors based on informed choice.

In France, two ways to address interdisciplinarity in connection with scientific challenges

Implementing a classroom project on renewable energies: scientific interdisciplinarity

In this CPD training, five disciplines are involved: physical and chemical sciences, biology, geology, mathematics, technology and geography. Participants, i.e. secondary-school teachers, are motivated by the aim of the course which is to implement an interdisciplinary project on renewable energies.

To this purpose, the training session provides tools dedicated to multi-disciplinary teams of teachers so that they can build and implement a classroom project on the issue of renewable energies. It allows teachers to improve the scientific and technical competencies needed to lead such a project. It also offers support to devise an interdisciplinary project.

The issue of the supply of electricity on an island, either a real or a virtual one, serves as a guiding thread throughout the training session.

The programme of the training allows to:

- start from the real example of the island of Sein (Brittany), in order to discover the pluridisciplinary aspects of renewable energies,
- write a classroom project scenario, related to the school’s particular context,
- discuss with scientists, instructors and colleagues to build the classroom project.

What is the purpose of travelling to extreme environments like Antarctica? From science to other disciplines

In this CPD training, several disciplines are involved, both scientific and non-scientific: physical and chemical sciences, biology, geology, mathematics, technology, French and English, history and geography. In addition to secondary teachers of these disciplines, school librarians are also mobilized. The motivation of all participants for dealing with the Antarctica is high since it provides the best example of an extreme environment.

Antarctica is also a land of rich promises for research, involving Natural Sciences, as well as Literature, History and Geography, but also Logistics and Engineering science, two fields that are especially needed to conduct a scientific exploration. Research in Antarctica proceeds from all these fields, and as such it allows triggering and leading an interdisciplinary activity about science in a classroom.

Interacting with scientists whose activity is related to Antarctica also enables to discover the day-to-day activity of researchers and to build a link between the science taught in the classroom and the science in progress.

The programme of this course enables:

- to devise and trigger a classroom project involving hard sciences and humanities;
- to discuss with Antarctica-based researchers about various aspects of their activity and life in Antarctica;
- to visit laboratories where the activity is partly based e.g. for the processing of data collected in Antarctica;
- to organise classroom visits of researchers and technicians.

3.2 CPD delivering

The various forms that can be developed to deliver CPD are not a trivial issue but one as important for effectiveness as the content itself.

Indeed, finding the adequate characteristics of CPD in terms of organisation over time and space are crucial on a pragmatic point of view –how to make CPD accessible to the majority of teachers- but also on a more fundamental point of view: how to enable teachers, who are isolated in their daily teaching practice, to take in charge their own professional development and at the same time contribute to form a learning community with their peers and other stakeholders not directly pertaining to the educational system.

LINKS partners do not intend to prescribe a list of recipes that could be implanted everywhere without adaptations, rather to show, like in the previous chapter related to CPD content, that some major elements, like **the duration**, and strategies, for instance **training trainers**, have been identified as relevant to deliver impactful CPD.

However it is important to mention here that delivery will be all the more effective where several forms are combined: **distance-learning** complementing face-to-face CPD, **provision of turnkey resources**... And the strength of each CPD activity will be maximised from its proactive association with others. Creating a cohesive system, especially **learning communities**, rather than providing isolated activities is the main lesson learnt.

3.2.1 Long-term CPD is a key objective...

Sustainable improvement requires long-term CPD investment

Within the LINKS partnership, we put our knowledge together to jointly develop recommendations for a long-term CPD vision. In doing so, we do not only condense our structural or content related knowledge, we also draw on scientific findings on CPD program developments. Hargreaves & Fink (2003) highlight that sustainable improvement requires investment in building long-term potential, like enhancing skills through continuous CPD activities. This is key because adopting IBSE requires deep professional changes regarding the posture, and to consider student learning in a new light.

In most countries, primary and secondary teachers do not know or use the IBSE methods in their teaching. In addition, in some countries, at primary level, only one teacher delivers all courses, including the science courses, while the majority of primary teachers either took literary studies (e.g. in France) or pedagogical studies with a mix of contents (e.g. Finland, Italy).

Helping them to change their teaching practices in a sustainable way supposes to engage them in many novelties: working in collaboration with their colleagues, in a spirit of interdisciplinarity, but also working with their management, the parents and the scientific community.

Moreover, the evolution of professional practices cannot be effective without going back and forth between moments of reflection outside the classroom and moments of implementation with students.

Finally, long-term CPD investment is also key because of the rapid changes and complexities in science subjects.

All the reasons mentioned above make obvious the impossibility of making profound transformations without allocating substantial time to CPD, over time and not only by providing intensive courses, even if these courses may be essential parts of CPD, especially at the beginning of the path.

Therefore, it is paramount that educators and teachers engage in life-long learning processes to be able to grasp innovative science and teaching developments.

Scientific Literacy and Long-term CPD

With IBSE activities, educational action research and further CPD activities within STEM, we do not only intend to promote academic competencies, we also aim to foster dialogue and debate capability, evaluation and reflection skills, ambiguity tolerance as well as the skill of community contested truth seeking. We consider these basic civic competencies as described in concepts of "scientific literacy" (Costa/ Mendel 2017) enhanceable by long-term CPD activities.

The varying length of "long-term"

Looking at the CPD programs within the LINKS partnership, we see varying temporal frames for long-term CPD activities. These reach from courses with duration of several weeks to offers for participation that last over several years. Long-term CPD is best served, when it helps to accomplish school and/or subject matter development (learning systems) in specific contexts. We consider it beneficial when actors engage in local and national CPD networks as CPD efforts find grounding in local communities of learners and educators.

However, even if a given duration is not fixed for CPD in the various countries and within countries themselves in the various programmes they may conduct, all partners agree on the general recommendation of 80 hours of professional development (Supovitz and Turner, 2000) to achieve significant change. But once again, this does not mean that no professional development is needed after this duration; iterative, life-long CPD should become the norm.

References:

Costa, R., Mendel, I. (2017). *Tatsächlich. Feministische Zugänge zur Wissenschaft vermitteln.* Critical Science Literacy. Wissenschaftskritik in der Schule. Lehrmaterialien. Online Ressource: http://genderplanet.univie.ac.at/sites/default/files/docs/lehrbuch_CSL_Tatsaechlich.pdf (Download 12.01.2018)

Fullan, M. (2006). *The future of educational change: system thinkers in action*. Journal of Educational Change, 7, 113–122.

Günther, E. (2015). *The ideal student.* Intersectional interferences in teaching STEM at universities. Paper presented at: 18. Techno-Ökonomie Kolloquium, Wien, Austria.

Hargreaves, A., & Fink, D. (2003). Sustaining leadership. Phi Delta Kappa, 84(9), 693–700

Krainer, K., Zehetmaier, S. (2013). *Inquiry-based learning for students, teachers, researchers, and representatives of educational administration and policy. Reflections on a nation-wide initiative fostering educational innovation.* In: ZDM - The International Journal on Mathematics Education, Vol. 45, 875 - 886, Springer Verlag GmbH.

Supovitz, J. A., & Turner, H. M. (2000). *The effects of professional development on science teaching practices and classroom culture.* Journal of Research in Science Teaching, 37, 963-980.

In Italy, long-term CPD develops individual capacities as well as those of the network

ANISN organizes only long term CPD for science teachers of all school levels (age of students from 4 to 16). Each centre plans each year a complex offer of multilevel courses tailored to teachers' expertises. CPD courses for beginners, advanced and expert teachers are, usually, the three main typologies. The effectiveness of long term CPD is the results of multiple and convergent characteristics of the PD actions promoted by the network in each centre. Some of them are summarized below:

- periodic face-to-face meetings (lasting at least 40 hours in total per year);
- classroom activities with optional peer-observation of teaching (at least 10 hours per year);
- free supply of kit-boxes for classroom activities;
- multi-years duration of CPD courses for beginner, advanced and expert teachers;
- opportunity to be involved in European projects on IBSE.

External evaluation has proven the positive impact on the didactic skills of teachers according to the type of CPD.

Over the time, a cohort of teachers involved in advanced courses for several years, took different role and responsibility in the local centres or at National level.

In UK, a unique programme of comprehensive support

ENTHUSE CPD supports STEM educators working in UK schools and colleges and responds to their current needs in professional learning and resources, whilst developing the knowledge, confidence and skills needed for a world-leading STEM education in the future.

The heart of the ENTHUSE offer are the **transformative, face-to-face residential opportunities at the National Centre**. This provides unique opportunities for leaders of STEM and classroom teachers across all phases to engage with intensive and highly practical support. Typically, such CPD will be two to five days in duration over one or two residential periods, with each day being worth 6 CPD hours. Those attending multi-residential CPD receive additional 'gap tasks', i.e. assignments which invite them to test the new learning on practice before they return for the next residential training period. These CPD arrangements provide teachers with time and support to reflect on and implement changes in their practice, with demonstrable impacts on young people.

ENTHUSE supports teachers, technicians and other educators in accessing and benefiting from subject-specific CPD in science and other closely related subjects. It does this by:

- Providing bursaries that enable teachers, technicians and support staff from state-funded schools to engage with intensive, often residential, face-to-face CPD at the National Centre in York
- Funding partners in Scotland (Scottish Schools Education Research Centre (SSERC), Wales (Techniquest) and Northern Ireland (Education Authorities of Northern Ireland-EANI)) to provide face-to-face CPD for teachers and technicians, appropriately tailored to national needs

- Supporting ENTHUSE Partnerships - groups of schools working together and being supported to address issues of STEM achievement and participation. A variant of this is the ENTHUSE Intensive Award, which provides schools in particularly challenging circumstances with tailored and sustained in-school support to begin their improvement journey
- Providing STEM Insight placements enabling teachers to spend up to two weeks with STEM employers or university departments, with 'wrap-around' CPD to ensure embedding of STEM careers back into school or college curricula
- Enabling access to a portfolio of online CPD supporting key aspects of STEM teaching, including subject knowledge, practical skills and assessment for learning.

In France, a 6-month training in partnership with CERN

One of the objectives of the Houses for science is to provide long-term CPD. This can be achieved by assembling several complementary short training sessions, or via a single long one. The following example illustrates the second way and deals with a long-term training programme organised in partnership with CERN (European Organisation for Nuclear Research) which title is "Matter: a key-concept from elementary to secondary school".

This 32-hour training programme aims to make attendees refine their perception of matter at microscopic scale and discover the advanced technologies used for research in physics of particles. Around the subject of matter, the goal is also for them to think about a progression of small notions adapted to children level and connected to class activities (conceptual storylines).

The 32 hours are structured in 6 steps, in a hybrid way: 18 hours in face to face (inside CERN) and 14 hours at distance (synchronous meetings and asynchronous moments).

As this training programme has been delivered 3 times (2014, 2015 and 2016) to 18-person groups and improved each year, it is now possible to highlight some relevant points:

- Encouraging attendees to work in groups on projects (according to affinities, teaching level, etc.), even more at distance, is a guarantee of success;
- Synchronous distance meetings are very effective to begin the programme (opening session) ("Ice-breaking", introducing one to each other, collecting expectations, explaining the programme, etc.) and for closing it (presenting groups' works, concluding);
- Face-to-face session in CERN is a high point where groups' projects can really start. It is also obviously a key moment to improve knowledge about fundamental research on matter;
- Asynchronous distance moments are appropriate for reading articles about pedagogical concepts, forming groups, analysing colleagues' works;
- Hybrid format allows attendees to take time to test some pedagogical concepts in the classroom or during teacher training sessions, and to share their experience afterwards.

3.2.2 ...But requires specific dissemination strategies and activities to be accessible for all teachers.

According to international teaching and learning survey (TALIS), teachers' interest to participate in long-lasting in-service teacher training programs focusing on professional development has been decreasing (Taajamo, Puhakka & Välijärvi, 2014). Hence, it's important to offer different kinds of models that are not too demanding to bring in to use for as many teachers as possible.

Different strategies have been experienced by LINKS partners and provide effective solutions to the problem of accessibility to long-term CPD.

3.2.2.1 Training of trainers

To initiate a large scale project to renovate the teaching of sciences, we think it is relevant to initially constitute a pool of trainers. This strategy is preferable for practical considerations as these trainers will then be able to multiply the actions of professional development by training teachers in turn. However, it is also relevant for another reason: at the beginning of the project, it is likely that the majority of the trainers involved would have the dominant pedagogical culture of the educational system that we wish to influence. If the project does not address the training of trainers but directly targets teachers, this choice will quickly become an obstacle as teachers potentially hear conflicting discourses on the pedagogy to be implemented in their classrooms.

Trainers can have different professional backgrounds, be recognized as such in the educational system, come from primary school, middle and high school, university, or even be professional scientists.

This plurality of professionals highly contributes to the application and dissemination of the principles of IBSE but requires first the creation of a solid common culture.

It is therefore recommended to offer these trainers a comprehensive professional development programme of sufficient duration and adapted to their different needs. This course may include moments of reflection and updates of scientific and pedagogical knowledge; it should integrate the know-how for the concrete implementation of teacher training and its collective analysis. It should also emphasize the need to cross the gaze by promoting interdisciplinary themes and collaborative work to facilitate the junction between primary and secondary levels.

The majority of the workshops scheduled throughout the course should follow the teaching principles of an IBSE adapted to adults. That is to say, they should allow trainers to build professional skills and update their scientific knowledge from an active reflection mainly practicing themselves experimentation, modelling, observation and interacting with the scientific world.

Indeed, it is ineffective to advocate pedagogical principles in a theoretical way without making them live. Let us note that this reflection is valid for trainers, teachers and students: to understand the principles underlying IBSE, all learners must live learning situations borrowed from social constructivism. These situations can, in a second time, be the object of analyses for a better understanding of their foundation.

The content of the course should allow trainers from different backgrounds to:

- Appropriate the principles of the scientific approach and science teaching based on inquiry;
- Have a mutual knowledge of their practices (scientific and pedagogical) by organising mutual visits (class visits, visits of laboratories, industrial sites);
- Understand how to jointly prepare and conduct a training course for teachers (co-construction);
- Reflect on the practices of each one: common points and differences between scientific practices and science teaching practices, analysis of training modalities to help teachers.
- The workshops shall also promote resources adapted to the classroom and to teachers' training:
- hands-on sessions which can be reinvested in teacher training,
- resources for the classroom and training: examples of training techniques, scenarios and concept maps on major scientific themes, classroom practice analyses based on videos or class visits, turnkey class sequences (see below).

Though the recommendations refer to 80 hours of professional development, the actions of the course to train the pool of trainers are effective from thirty hours. They can be planned over two years for example, the long term creating group cohesion that energises the work of trainers and promotes the circulation of experiences, know-how and the emergence of new ideas.

It is important to empower all trainers in a given area in order to form a real network. It may be useful to create a specific online collaborative space. This space facilitates formal and informal exchanges between the various highlights of the course, as well as the sharing of resources and practical experiences.

Moreover, this experience of networking allows trainers to measure the effectiveness of the learning communities they will then initiate and support at the level of the teachers they will train.

Finally, it is important, as the project progresses, to allow trainers from the network to share their experience with less experienced trainers, becoming trainers of trainers.

Indeed, the pool of trainers should be considered as a dynamic and unclosed network that expands and renews itself over the years to secure its own sustainability.

In Italy, mobilizing trainers from international to local scale

The structure of each IBSE ANISN Centre involves 5-8 local trainers who collaborate in implementing CPD and carry out various activities of the centre, as developing new resources, working in group with scientists and supporting colleagues in planning and conducting classroom activities.

In addition the centre structure includes national trainers, who are selected among the local trainers with an advanced level of expertise. They act as trainers both in their local centre and in other centres of the national network.

The training of local and national trainers is a key strategy of the network in order to promote the professional growth of everybody involved. It is based on the following actions:

- some trainers are trained at European level, thanks to the collaborations with other IBSE reference centres and/or the participation in European projects;
- specific trainings are organized at national level, through summer schools or during two-day intensive courses;
- special trainings are carried out at local level by international experts.

For instance, in the framework of the School for Inquiry project (in partnership with Ministry of Education and the research institution: Zoological Station Anton Dohrn in Naples), free of charge residential National summer schools (4-5 days) are organized for the network's trainers. The close cooperation with scientists and IBSE international experts enhances the collaboration among different CPD actors and trainers belonging to different local centres strengthening their specific competences, sharing resources, strategic actions according to a system vision and facilitating the future cooperation at distance.

As mediators for exchanging experiences, strategies, tools and learning paths, trainers contribute to strengthening the sense of belonging to a broader learning community, which expands from local to national and international level.

In UK, developing local facilitators through their accreditation

As part of its commitment to supporting the school-led model of professional learning and self-improvement, STEM Learning offers an extensive range of CPD courses designed to equip school based colleagues (teachers and technicians) with the skills to become an effective facilitator of subject specific CPD. Participants of such courses explore in detail the research and ideas about what makes effective CPD, how to implement these principles on practice and how to quality assure and assess the impact of the CPD they facilitate.

Developing CPD facilitators also helps provide quality assurance and ensures consistency of delivery across the whole National STEM Learning Network. To support this process, STEM Learning has launched a new accreditation scheme for facilitators of STEM-specific CPD.

STEM Learning will continue to roll out its CPD Quality Mark, an accreditation scheme for CPD facilitators, which assures the skills and appropriate experience of those delivering CPD. By September 2018, the aim is for all Network CPD to be delivered by people holding the full CPD Quality Mark – around 350 individuals. By September 2019, it is expected all facilitators working with STEM Learning, whether in York, through Science Learning Partnerships, or in other roles across the network, to hold the accreditation.

3.2.2.2 Distance learning/ use of digital tools

The integration of Massive Open Online MOOCs as part of the support for IBSE is evident across most countries. It not only increases reach but also is more inclusive for those teachers who cannot afford CPD or are not able to attend a centre. This type of offer can also be combined at local level with face to face support in a blended program.

The duration of MOOCs varies with an average on nine guided learning hours being available over a period of weeks or months. Retention rates for online CPD is still a challenge so shorter MOOCs, providing a personalised pathway focusing on strands of IBSE have been impactful where this hypothesis for support and learning has been tested. It has been more challenging where IBSE has been addressed in its entirety by online distance learning. When modules have been designed to incorporate and promote the implementation of new ideas and strategies in the form of action research, the impact of such support has been more evident.

Identified advantages of this approach have been that online distance learning provides a more flexibility and also opportunity to network and share learning with others. The non-confrontational and private nature of online learning enables learners to acknowledge misconceptions that they might not have done in face-to-face training.

Design of online learning is multi-modal by nature-teachers may be invited to practice inquiry at home, watch scientific clarification clips and analyse class science sessions videos. They may be asked to test new science activities in the classroom and peer-share their experiences. Programmes also include live sessions (web-conferences), involving scientific or industrial researchers and pedagogical experts.

Subjects dealt with range from matter and energy to practical science in biology, chemistry and physics to Getting started with Practical science in the primary classroom. Critical thinking and Science of Learning are currently under development.

Enrolment to online CPD ranges from a few hundred participants to 12,000 including the international community. Retention rates remain the challenge with an average of 23% of participants completing the entire online CPD.

In France, developing Massive Open Online Courses on IBSE

Addressing IBSE in an entirely distance learning programme can appear to be an insurmountable challenge. Indeed, except for a strictly theoretical approach, this implies practicing and sharing with others, which is obviously more difficult at distance. On the other hand, distance learning gives more flexibility and opportunity to provide motivating training forms. Thus, the Houses for science have chosen to take up the challenge since 2015, offering Massive Open Online Courses (MOOC) on science topics, with an IBSE approach.

Hosted on the French ministry of Education distance learning platform, these courses offer teachers a way to enhance their knowledge on specific topics, and to improve their pedagogical skills on teaching science, following innovative training modalities.

The training programme requires nine working hours, corresponding to seven steps (each step takes from 1 to 2 hours), distributed on three months. During the four first steps, teachers are invited to practice inquiry at home, watch scientific clarification clips and analyse class science sessions videos. The second part of the programme consists of testing new science activities in the classroom and peer-sharing experiences. The programme also includes live sessions (web-conferences), involving scientific or industrial researchers and pedagogical experts.

During the course, a global supervision is provided by *La main à la pâte* team, which sends periodic messages to all participants, in order to announce each new step and provide global analysis of main successes and difficulties. In addition, closer guidance can be carried out by local trainers.

Two different courses have been implemented so far: one about matter, and the other about energy. A third one, about critical thinking, is currently under development.

About 3,000 teachers have already been registered to Houses for science Massive Open Online Courses, with an average attending rate reaching 50%. Attendees appreciate content attractiveness, scientific interventions and concreteness of video class sessions examples.

In Finland, online courses to learn how to use digital content

In the years 2013–2014, LUMA Centre Finland organised online courses on electronic learning environments for all LUMA teachers in Finland. In 2013, there were two courses: one basic level and one advanced level course. Courses turned out to be popular to such a degree that LUMA Centre Finland had to organise an extra course (basic level) in 2014. In 2013, courses were accomplished by 67 teachers and the extra course in 2014 was accomplished by 31 teachers. Enrolled teachers were from all over Finland.

The goal of the basic level course was to construct basic knowledge on how to use digital content in electronic learning context. It included five learning modules:

1. Theory of blended learning
2. Media types and copyrights in education
3. Subject specific ICT-tools (e.g. material repositories, software, and applications)
4. Creative commons content and open access materials
5. Content publishing and social media.

The advanced course was built upon the basic course. In the advanced level course, all teachers carried out a small design research project where they produced ICT-based learning material suitable for their own teaching.

The course was organised with the aid of Peda.net learning platform hosted by the University of Jyväskylä in Finland. It is free for all users for individual learning purposes. This platform was chosen because it is built to support lifelong learning; users never lose their access to resources or feedback.

3.2.2.3 Turnkey resources and activities

As well as the need for high quality, formal CPD opportunities to support teachers in making career step-changes from novice to subject leader, self-directed learning is a key feature of day to day professional development. It allows teachers to set their own goals and identify the activities they wish to try out to develop their professional expertise.

The use of resources to develop understanding of different pedagogical strategies, improve subject knowledge and implement STEM education in the class is a very common form of self-directed professional development amongst teachers.

Turnkey resources are especially important for freshly qualified teachers; novice teachers' transition from education to working life (induction) is seen as a major challenge worldwide (e.g. Handolin-Kiilo, 2015 & Heikkinen, Markkanen, Pennanen & Tynjälä, 2014). The beginning of novice teacher's career is full of stressful and time-consuming challenges and learning new things that he or she must face and defeat to continue the teacher's career (e.g. Taimisto, 2013). Challenges for novice teachers include issues concerning practical working (experiments), assessment, planning, workload, large group sizes in the class and subject content, to name but a few. In particular, the workload is felt as a great challenge for novice teachers (Handolin-Kiilo, 2015).

Workload in teacher's profession is not solely a problem for novice teachers; also more experienced teachers are busy and need materials with a low threshold that they can use to develop and improve their teaching furthermore without too much of extra effort (e.g. Ulvik et al, 2006). This is particularly useful when teaching a topic or new age group for the first time and immediate support is required

Based on evaluation of teachers' needs, different kinds of turnkey resources have been offered already. These include (but are not limited) pedagogical modules, worksheets for teachers and students, and kit-boxes with all the materials and equipment needed for the implementation of various school science experiments.

Teachers can borrow the kit-boxes, and other equipment, without any charge when they need them so they do not have to use any resources from their schools, per se. It is important to continue developing various sorts of ready-to-use materials, such as hands-on activities and worksheets, for learners together with the latest research information and pedagogical tools to support teachers.

Therefore, contextualising resources for trainee teachers supports both self-directed professional development and in-school mentoring.

However, a large choice of resources can be bewildering to inexperienced practitioners who are not sure what they are looking for and perhaps do not have the expertise to judge the quality of resources they find. A bank of well curated, online resources which are focused on specific areas of professional development can provide teachers with quick access to specialist advice and guidance, allowing teachers to construct their own understanding of effective practice through inquiry, reflection and discussion with peers and mentors.

And of course, professional development remains the best way to facilitate the ownership and use of resources; that is why resources should be as much as possible provided in the frame of other professional development activities: training sessions, meetings, etc.

References:

Handolin-Kiilo, H. (2015). *Kemian noviisiopettajien osaaminen ja sen tukeminen työelämän ensimmäisinä vuosina* (Chemistry novice teachers' professional knowledge, know-how and the support need in professional development during their first years in working life). Licenciate thesis.

Heikkinen, H., Markkanen, I., Pennanen, M. & Tynjälä, P. (2014). In (Ed.). *Opettajan-koulutuksen tilannekatsaus: Muistiot 2014:4* (Teacher training reports: Memos 2014:4). (s 45-54). Helsinki, Opetushallitus.

Taimisto, S. (2013). *Noviisiopettajan ensimmäiset kuukaudet työelämässä* (Novice teachers' first months in working life). Master thesis. Jyväskylän Yliopisto. Retrieved from: http://urn.fi/URN:NBN:fi:jyu-201306252039

Taajamo, M., Puhakka, E., & Välijärvi, J. (2014). Opetuksen ja oppimisen kansainvälinen tutkimus TALIS 2013: Yläkoulun ensituloksia. Opetus- ja kulttuuriministeriön julkaisuja 2014:15.

Ulvik, M. Smith, K. & Helleve, I. (2009). Novice in secondary school – the coin has two sides. *Teaching and teacher education*, 25, 835–842.

In France, developing turnkey resources linked to the themes of CPD trainings

It is sometimes difficult for teachers to reinvest the content seen during the CPD session. Actually, these training sessions are often short; the contents are thus dense, in the detriment sometimes of the time dedicated to the operational implementation in the classroom.

To solve this problem, the House for science in Midi-Pyrénées has created educational turnkeys resources linked to the themes of its CPD trainings, as for example 'Molecular gastronomy: principles of physics and chemistry in a kitchen', 'The Canal du Midi: scientific and historical approach'.

These resources contain at the same time detailed pedagogical activities for the pupils, but also reminder of the essential scientific knowledge and bibliography allowing to find additional resources. These resources are in free access on the internet or can be bought in library. Some of these resources appear in the form of kit and also contain scientific material for experiment, sometimes difficult to find in schools. For example 'The classification of animals' with collections of plastic animals to be classified, 'How to play with mathematics' containing specific geometrical forms, or 'the human body in action' which contains connected watches with movement analysis software. The teachers can then borrow these kits for a period of several weeks to conduct science lessons in class.

In UK, turnkey resources are developed around each of the Teachers Standards themes

Secondary science teachers in the UK are required to teach outside their specialism so, for example, a biology teacher will also need to be confident in teaching physics and chemistry. This means that trainee teachers in particular have a huge amount of subject and pedagogical knowledge to acquire. In England, The Teachers' Standards are used to assess all trainees working towards Qualified Teacher Status (QTS), and all those completing their statutory induction period after qualifying, providing a focus for areas of improvement. In response to this resources have been curated around each of the Teachers Standards themes which exemplify good classroom practice, provide sound pedagogical content knowledge and subject knowledge. These are combined with hand-picked teaching activities and resources matched to each topic across the three science curricula. These resources have been chosen because they include evidence-based teaching approaches, information on common misconceptions and explanations of the science to aid teachers' self-directed learning.

Reference:

Teachers' Standards Guidance for school leaders, school staff and governing bodies (July 2011), Department for Education. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/665520/Teachers__Standards.pdf

In Austria, two examples of turnkey resources: the "knowledge wonder box" and the "rucksack for a scientific journey"

In addition to TALENTE REGIONAL projects, the Austrian Research Promotion Agency (FFG - national funding agency for industrial research and development in Austria) offers grants for schools and kindergartens to implement materials and methods out of projects. Per project, there are 10 grants available, each mounting to € 1.000. The money can be used to either acquire ready-to-use materials, or to take part in project activities or to carry out self-developed operations.

The "NaturErlebnisPark Science Education Centre" offers for these so called "Cooperation schools" a set of materials ready to use in the classroom. The "knowledge wonder box" contains hands-on activities and worksheets for children as well as background information and pedagogical tools for teachers. The "rucksack for a scientific journey" holds more complex activity ideas and materials to be used for outdoor quests and inquiry-based homework to be done together with parents.

Classroom Package "Knowledge Wonder Box"

If wanted, schools can get educational support through the science education centre's staff. Our experience proves that providing low-threshold facilities encourages teachers and schools with little experience in IBSE to carry out small projects.

Turnkey materials are also a help for poorly equipped schools who do not have the resources to invest in didactic materials for IBSE. All cooperation schools have to reflect their practice and write a project report.

In Italy, kit-boxes are available free of charge

Many ready-to-use resources are available to the trainees at ANISN IBSE CPD Centres. Each centre offers: detailed description of paths of activities developed during the CPD; supplementary worksheets for teachers and students; kit-boxes with all the materials and equipment needed for the implementation in the classroom.

These resources greatly facilitate the teachers in facing the challenges of the implementation of IBSE at school. They are essential especially for the beginners, representing also a strategic incentive in running the activities with students overcoming problems of low equipped school and time consuming of the teachers. All the resources, as well as the entire training course, are free of charge for the trainees. Moreover, an alternating system in the distribution of the kit-boxes, allows covering the various requests according to the school planning. Finally, the presence at the training course of several teachers belonging to the same school, facilitates the distribution and use of materials encouraging the dissemination within the school. In each school, a reference teacher is identified to create a system of network of reference persons associated to schools network. In some IBSE Centres, the kit-boxes are kept in reference schools as node of local school networks. This peripheral organization decreases the organisational burden of the IBSE Centre. Indeed, over the years, some schools have purchased many materials contained in the kit-boxes making them a part of the school labs equipment. Most experienced teachers have become more autonomous in choosing and using materials and equipment as kit-boxes.

3.2.2.4 Learning communities

Learning communities play a crucial role in enhancing professional development of teachers. The process to build them is not a generic "one size" fits all, but needs a continuous shared self-reflection and multistep strategies built through sharing, comparison, critical reflection, to improve teaching-learning processes, to create an "enriched environment" to drive students closer to science, to let them perceive how scientific knowledge is constantly evolving and linked to everyday life.

Among many, few key factors seem to act in building a sense of community (McMillan& Chavis, 1986)[1]: belonging, influence, satisfaction of individual needs and management of emotional events. Aware of these factors, in European contexts, different strategies and organisational methods have been adopted to guarantee and sustain the process rooted on them and coherent with a socio-constructivist approach.

Learning communities are open environment, which expands and renews itself over the years to ensure its sustainability and duration. The extension of a learning community could be different, from local (a school, schools' district, schools' region) to National and to International levels. Interconnected LCs of different size expands the "group identity", reinforcing and enriching the single ones at its own level. Different tools and strategies could be adopted at different dimensions even if some constant factors highlighted above represent a common frame at different scale. A cycle of continuous improvement to engage in inquiry, action research, data analysis, planning, implementation, reflection, and evaluation are always applied2 (Hord S.M, (2004). To be attractive, a learning community has to be advantageous for the members both on professional and personal aspects.

The existence of a reference place where the teachers can meet in person periodically (and along the years) for training courses and/or for specific working groups plays an important role in breeding the processes of mutual sharing and confidence, engine for transformative professional processes. Learning communities in schools have the potential to provide school-wide, on-going support within the teacher's own context sharing collective responsibility for the learning of all students within the school. Collective responsibility brings together the entire education community, including members of the education workforce - teachers, support staff, school system staff, and administrators - as well as families, policy makers, and other stakeholders, to increase effective teaching in every classroom. Within learning communities, peer accountability rather than formal or administrative accountability ignites commitment to professional learning.

[1] McMillan, D. W. & Chavis D. M. (1986). *Sense of community: A definition and theory.* Journal of Community Psychology. Volume 14, January 1986. Pages 6–2.
[2] Hord, S.M. (Ed.). (2004). *Learning together, leading together: Changing schools through professional learning communities.* New York: Teachers College Press & NSDC.

Professional development has important links with professional learning communities across many countries3 (TALIS survey, 2013). Cooperative PD is particularly appropriate for developing the values, norms, and shared expectations among teachers that learning communities are known for. Analysis of TALIS data shows that teachers who participate in co-operative learning professional development also experience higher levels of participation in a learning community in their schools as opposed to when they participate in workshop or seminar professional development.

Therefore, it is important to strengthen the importance of these aspects, also during the training courses of the trainers to foster learning communities among teachers. Trainers could play the role to facilitate, support, motivate and help teachers belonging to the learning community in in-depth, systematic, collaborative activities of professional development. Learning community members are accountable to one another to achieve the shared goals and work in transparent, authentic settings that support their improvement.

In the last decade, the availability of online collaborative spaces has assumed more relevance also in educational context and progressively they are becoming certainly the more extensive ones. They are generally used for formal and informal exchanges among different actors of the learning processes, to enhance the availability of resources and experiences, to provide distance courses (webinar, MOOC), able to be more responsive to general or specific needs of teachers.

Technology facilitates and expands community interaction, learning, resource archiving and sharing, knowledge construction and sharing. Some educators may meet with peers virtually in local or global communities to focus on individual, team, school, or school system improvement goals. Often supported through technology, cross-community communication within schools, across schools, and among school systems reinforces shared goals, promotes knowledge construction and sharing, strengthens coherence, taps educators' expertise, and increases access to and use of resources.

Cross-fertilization among different dimension of learning communities through educators and teachers as vectors of interactions is a challenge to face to achieve specific and global goals.

[3] OECD. (2013). Teaching and Learning International Survey TALIS.

In France, learning communities are used to widen the coverage

One of the challenges that the MPLS-Midi-Pyrénées had to face is to be able to train teachers on a very large territory. One of the solutions to solve this problem was to set up learning communities providing them blended-learning activities, combining face-to-face sessions, online courses, remote tutoring. These modules of our blended-learning activities have duration of 40 hours per year, over 2 years. They mobilize each year the teachers 6 time on-line (3 sessions of 2 hours with the whole group after school) and 4 days in face-to-face (2 days at the beginning of the school year, 2 days at the end).

The first online session is dedicated to the discovery of DevPro, a platform of collaborative work, to make sure of a good appropriation of the platform by the teachers. This tool possesses functionalities such as: warehouse, chat, forum and a videoconferencing system. All the exchanges between members of the community are made from this platform; all the contents are accessible only to teachers' community, as well as to trainer and scientists involved.

Concerning the contents, it is first of all about the updating of scientific knowledge during the first sessions, comes then a pedagogical reflection in face-to-face with the whole group. This is a very important bonding moment to create an atmosphere of trust and mutual understanding inside the community. This moment is followed by an individual work (or in small group) of elaboration of class activities (tutored online by the trainer), then from a final session with the intervention of a researcher most of the time linking the scientific topic to societal issues. The same pattern is reproduced on year 2, focusing on the transfer in the classes, peer to peer collaboration, and discovery of turnkey resources.

In Austria, a peer-learning community on WIKI

The internet-platform IMST WIKI contains a multitude of good-practice-examples of IMST thematic program projects. Each year about 4.500 teachers either develop classroom innovations or get connected in regional networks to improve teaching in mathematics, science, informatics and German language. Over 1000 project descriptions provide insights into innovative materials and methods but also plain and direct explanations about project experiences, evaluation results and problems that may have occurred. All Austrian teachers are invited to pick up ideas and materials and benefit from their colleagues' knowledge and expertise. Among the IMST community the IMST WIKI serves as an efficient knowledge connecting link. Results of the yearlong development of teaching materials are collected on this platform and provided for further use in classrooms.

Interdisciplinary Science Cafes (NEP)

Vivid interdisciplinary learning communities can successfully be built among formal educational institutions, after-school care centres, out-of-school youth work, university students and scientists. It is useful, if one (intermediary) institution assumes responsibility for the coordination of all partners. In NaturErlebnisPark Science Education Centre especially periodic meetings succeeded to combine an activity for socializing among the partners, a theoretical or practical input as well as a joint task, e.g. developing educational materials together, organizing an event or doing educational research. Across the borders of scientific disciplines personal contacts and a shared knowledge base arise and create an atmosphere that stimulates learning from each other and with each other.

In Finland, learning communities are important for remote areas

There are about 25 schools near Rovaniemi where LUMA Centre Lapland is located. Outside Rovaniemi area, there are approximately 60 schools. The distances to these schools range from 70 to 500 km from LUMA Centre Lapland.

Studying in virtual environments is one way to reach teachers outside Rovaniemi area. LUMA Centre Lapland has organized a few collaborative video-based projects in which 4 – 5 elementary school classes from remote villages studied online together by doing science experiments and sharing short video documentaries. These projects include using both pre-recorded material and live communications over the Internet, depending on the phase of the project. The projects also functioned as in-service CPD training for the participating teachers. This year, a rocket building club for elementary school pupils takes place simultaneously in five communities.

However, we always prefer to combine personal communication with our virtual activities. Meeting teachers in person seems to be crucial in Lapland in general. To advertise our LUMA Centre, we have given succinct workshops to teachers all over Lapland. To encourage classes to participate in the StarT science fair, we have organized information evenings, visited teachers' meetings in schools, talked to headmasters of schools, and visited schools in Rovaniemi as well as in other municipalities in Lapland. Once a personal contact is established, it is easier to maintain it via e-mail, phone, or video calls.

In Italy, learning communities are connected from the national to the school level

The creation and the implementation of learning communities have always been the core of the systemic vision of the network of IBSE Centres in Italy, since the very beginning. It is a long-term goal, which needs time, continuity and strategic actions, in order to breakdown cultural and professional barriers.

As results of processes purposely activated, interconnected learning communities have been created at three different levels: at National network level, at local IBSE centres level and at schools level.

Different and effective strategies have been developed in each of the three levels:

- At National network level: 1. Cooperative actions (at distance and face-to-face) among IBSE centres' responsible. 2. Common National trainings of local trainers 3. Sharing of training models and educational resources.
- At the IBSE centres level: 1. Identification of a reference place (university, research centre, museum, rarely school) for the training course and easily available to teachers (or trainers), where they can freely meet, work in group, found resources, store and pick up materials, etc. 2. Identification of one or two reference people with specific responsibility (heads of the centre) 3. Long–term CPD courses that have favoured mutual knowledge and increased confidence.
- At the Schools level: 1. Formal commitment of the headmasters. 2. Voluntary participation of, at least, two teachers from each school. 3. Agreements among schools in the same geographic area, in order to reinforce their cooperation and the common participation of their schools and teachers in CPD programmes led by the local IBSE center.

The learning communities built at different scale are autonomous but interconnected. ANISN is a community itself and its identity has represented an enhancer factor, even if it was not sufficient in itself. The powerful role of learning communities in sustaining long-term transformative process and in increasing the impact is evidenced by the multi-years attendance of the teachers, the implementation of the centres over time, and the number of teachers involved within each school.

In UK, the school-led professional development and learning model

Recently, there has been a drive towards a school-led model of professional development and learning with considerable value placed on school-to-school collaboration. It is argued that when professional learning takes place in a school or school partnership it is more likely to address their actual needs for development, hence more likely to be embedded into practice and lead to sustainable improvement for the whole school.

Building on this evidence from research and best-practice STEM Learning has expanded their model of subject-specific CPD through the ENTHUSE partnership programme (EPP) which funds groups of schools (between 4 and 8) working in partnership and using CPD to improve teaching and learning of STEM subjects. The schools work together to address issues of underachievement in science, technology, engineering and mathematics, the STEM subjects, so as to raise achievement in these subjects, narrow the gap between underperforming pupils and increase progression to STEM subjects post-16.

The partnerships are awarded a bursary of up to £12,000 which can be used to access a full range of CPD through the STEM Learning network from residential intensive CPD at the National STEM Learning centre in York to shorter single day CPD with the science learning partnerships in the regions. They can also access a 5 day industrial or university placement through the STEM Insight programme to update their knowledge of STEM careers as many teachers have little experience of industry. Through the STEM Ambassador programme, they can bring people into schools who are already following STEM careers to work with students and raise their awareness of the opportunities within STEM industries.

The first cohorts engaged in ENTHUSE Partnership were primary schools working together with perhaps one secondary school sharing good practice through CPD across the partnership. Most recent partnerships consist of secondary schools and FE colleges and they have an emphasis on raising awareness of STEM careers as well as addressing any underachievement in STEM subjects.

Internal and independently commissioned evaluations show that the programme is very effective in achieving a broad range of positive outcomes for educators and young people in participating schools, bringing significant and sustainable impact for schools and local communities. It also gives evidence confirming that many schools choose to continue working as a partnership after the end of the programme so that they can continue enjoying benefits of school-to-school collaboration in STEM subjects.

3.3 Who do we work for, who do we work with?

It seems these two questions could be easily answered: all CPD providers work for teachers –and for children in last instance- and mobilise dedicated expert staff to this purpose, whatever their status and name: trainer, educator, tutor, instructor…

However, these questions are not purely rhetorical and LINKS partners consider that they are only partially answered by traditional CPD delivery.

Targeting teachers, though obvious, does not tell anything about the way we consider them when providing them with CPD. Do we address only individuals or also a group and which group: level groups, **primary vs secondary, or both together?** Do we create **bridges between pre-service and in-service teachers?** And do we consider their **school environments** while we work with them?

In the same logic, involving people not only to deliver CPD classical courses but to support a whole learning journey throughout teachers' careers supposes to associate a diversity of players who can give useful inputs and create a relation with teachers where mutual learning is central. LINKS partners have chosen to present here the work they have developed so far with two categories: **tertiary students** and **scientists** but surely others could contribute with valuable support.

3.3.1 How do we target CPD?

Usually CPD provider target only in-service teachers and they address their needs differently according to their level of teaching (primary or secondary).

Beyond these regular approaches, LINKS partners also propose alternative ways to address teachers, regardless of borders. Their efforts towards more interdisciplinarity in CPD (see above) has succeeded in qualifying the differences between scientific disciplines, but other boundaries linked to the position of teachers in the educational system are also challenged.

3.3.1.1 Common CPD for primary and secondary

The transition from primary to secondary school is a significant moment in a child's education and means some major changes for all children. Most will be better able to cope with these when this transition is prepared. A well-aimed transition plan avoids the need for a 'clean slate' approach where science teaching at secondary school will start 'from scratch', assuming that the incoming students know little about science or that what they do know is so variable that it would be better to start again.

The Educational system has historically made a sharp distinction between primary teachers and secondary teachers.

The pre-service teacher education is given at universities and at teacher training schools. Though all students have to get a master degree, they follow different curricula according to their future position as first or second degree teachers: multiple disciplinary curriculum for primary students and disciplinary curriculum for secondary students.

Moreover, the professional environments and also CPD programmes are quite different between the primary teachers and secondary teachers. Generally, while primary school teachers have good pedagogical knowledge and a variable level of scientific knowledge, secondary school teachers have deeper scientific content, but on a specific domain,. That is why most of the CPD for primary teachers is to give them a better level of subject content knowledge (SCK) with some limited input on pedagogical knowledge. However, lower secondary CPD is also mainly focused on SCK whilst the upper secondary CPD is focused on the "cutting-edge" subject content knowledge.

It is therefore very interesting to seize the opportunity to propose common Continuous Professional Development actions to primary and secondary teachers, not only for the sake of individual Professional Development, but also to favour interdegree sharing of good practices between teachers who do not meet often and whose professional environments may be quite different. Such common activities may thus facilitate the fostering of local peer communities with quite dissipated school borders.

However, a difficulty is that both teacher categories have different needs and expectations regarding the possible outcomes of the CPD actions.

The content should be focused on the content that teachers teach: ideally, the PD should be aligned with both primary and secondary programmes, providing coherence for teachers. The CPD action will identify a topic that is tackled throughout primary and secondary schools: this overlap makes it of paramount importance for the teachers of both degrees to know about what is done in the other degree.

An interdegree CPD action should also provide content that supports collaboration, typically in job-embedded contexts: it should propose CPD actions related to the improvement of knowledge or competences, and their transposition to the classroom teaching practices.

In fact, to provide coaching and expert support, the CPD action should be devised and led by an interdegree team associating one or several scientific advisors with instructors specialised in 1st degree and 2nd degree.

Finally, interdegree CPD actions should offer opportunities for feedback and reflection: the traditional episodic and fragmented approach to PD does not afford the time necessary for learning that is rigorous and cumulative. Offering multiple opportunities for teachers to engage in learning around different content has a greater chance of transforming collaborations between primary and secondary teachers.

Let us remark that timeframe related difficulties must not be underestimated: the calendars for CPD actions for 1st degree and 2nd degree teachers do not match well and it is thus quite difficult to gather teachers of both degrees during the same period and during several sessions.

Nonetheless, it makes sense that collaboration between 1st and 2nd degree teachers is an important feature of CPD and it should be promoted.

References:

Darling-Hammond, L., Hyler, M. E., Gardner, M. (2017). *Effective Teacher Professional Development*. Palo Alto, CA: Learning Policy.

Higgins, S., Cordingley, P., Greany, T., Coe, R. (2015). *Developing Great Teaching: Lessons from the international reviews into effective professional development*. University of Durham; Teacher Development Trust.

In Austria, the "Keep moving" project

The "Keep moving" project of "NaturErlebnisPark Science Education Centre" was driven by a regional consortium structure. All educational institutions of a rural community (kindergarten, primary schools, lower secondary schools and one upper secondary school) formed together with scientists, economic operators, and regional authorities an active innovation team. All participants worked as equal partners and contributed their specific expertise. Scientists and technicians introduced the other members of the work group into technical aspects of the project topic. The teachers gained a lot of new skills. Together, the group worked out didactic methods to deal with the topic in different levels of education. During the project year, several activities regarding the topic "regional mobility", led by the teachers involved in the working group, took place where children collaborated in mixed age groups. Step by step, the children got deeper into the topic by exploring the physical, geographical and social aspects of mobility until they finally participated in a serious infrastructural research study with the regional university for applied sciences.

Keep moving: Engaging all levels of education in a community into a participatory research project.

The main benefit of this setting is that it builds upon existing cooperation and personal relations within a community. The new impulses and shared project experiences of the common CPD activities offer a considerable potential for sustainable changes and innovations.

In Finland, Maths CPD for primary and secondary teachers

As a part of LUMA Finland Development Programme, a joint CPD education series (Matikkakukko = Mathematics Rooster) for primary and lower secondary level teachers during the academic year 2015-2016 was organized. Out of the 27 teachers participating, 11 were primary level teachers whilst others were either mathematics subject teachers or special education teachers working at lower secondary level. Mutual sessions enabled networking and discussions over school level borders. This way of implementation was applauded by the participants, and the feedback was thoroughly positive.

During the series, the concepts of mathematics were approached by means of activating methods and concrete learning equipment. The emphasis was on supporting and guiding teachers in grasping the meanings of concepts, not so much in calculation per se.

During these CPD sessions, teachers received practical methods and tools to bring mathematical concepts closer to pupils' everyday life. Besides, teachers were expected to enhance their understanding about the connections between concepts and mathematics structure from the viewpoint of geometry and algebra. The framework for the series is seen in Table 1.

Table 1: The themes addressed during the CPD education series labelled as Matikkakukko (Mathematics Rooster).

Session	Theme addressed (P = primary level, LS = lower secondary level)
1	P & LS: Introduction and orientation towards teaching
2	P: Development of the concept of number. LS: Basic mathematical operations
3	P: Clarifying verbal tasks.
4	P & LS: Understanding the decimal system
5	P: Fractions, decimals, and per cents. LS: Functions and ratios
6	P & LS: Fractions, decimals, per cents, and calculations
7	P & LS: Geometry
8	P & LS: Geometry
9	P & LS: Measuring and unit conversions
10	P: What's the problem with the multiplication table LS: Functions and graphs
11	P: Divisions and divisibility
12	P & LS: Numbers sequences with activating methods and assessment
13	P: Producing materials LS: Workshop for lower secondary level related to sequences
14	P & LS: Closure and evaluation

In Italy, common CPD for primary and secondary is in line with the organisation of schools themselves

Common CPD for primary and secondary school teachers is a strategy shared in all the centres of the network since seven years. PD courses for teachers with different competences and from schools of different levels constitutes a key added value in IBSE training courses, but, based on our experiences, it is not enough to drive transformative processes if the meetings are not periodic and do not span on several months of the school year, as happened in all the local centres. IBSE takes time to be embraced by teachers, as well as breaking cultural barriers between primary and secondary school teachers to create cross-fertilization being aware of the great mutual benefits. In Italy, these processes took the great contextual advantage (introduced in 2010) of the creation of comprehensive schools where kindergarten-primary-lower secondary schools were jointed as a whole comprehensive school. Therefore, the collaboration processes among trainees more easily continues not only as peer community connected to the local centre but also within the schools' context promoting long lasting links among teachers and students belonging to different school levels. The resources developed to train trainees belonging to both school levels have been organized in sequences of growing complexity with a "vertical" development that allows to set and use them according with school level, specific students' background or teaching aims, but being aware of the full path.

Common CPD for teachers belonging to different grade levels of school have proved their efficacy also for lower and high secondary school in six local centres. In the framework of AMGEN Teach project, supported by AMGEN Foundation and coordinated at European level by European Schoolnet. ANISN, as National provider has organized for four years common CPD courses for secondary (lower and high) Science teachers focused on IBSE resources on Life Sciences topics. On the base of external evaluation reports also these common CPD courses have proved their positive efficacy and impact on teachers.

3.3.1.2 Strong link between pre-service and in-service PD

Pre-service teacher education is given at universities and possibly at teacher training schools whereas education related to in-service teachers' professional development might be given by stakeholders that do not operate under university jurisdiction but who might be independent, possibly commercial operators. Naturally, this sets some challenges, if not constraints, for linking pre-service and in-service professional development.

Optimally, professional development of teachers should be a continuum that starts during their pre-service studies at university and continues for their entire in-service teacher career (Aksela, 2010). Obviously, such strategy is sensitive for all types of changes in society, such as curriculum reforms, but it also gives an idea about a possible link and dialogue that pre-service and in-service professional development could have.

The evident pro of linking pre-service and in-service PD comes from the interaction between these two groups; one can always benefit from facing people with alternating background but similar interests. This is especially fruitful in this case as "experience" can meet "fresh ideas". Another pro emerges from the fact that typically pre-service teacher training at universities is based on the latest research findings from the area, and in-service teachers can evidently benefit from these if addressed in CPD sessions, as they might not have chances to face those in their profession otherwise. The third evident pro is that if same educators execute PD sessions for both groups, the educators will automatically have two different feedback sources that can benefit them with other groups. For example, in-services teachers' perspective and experiences from ordinary schools might be an important asset for pre-service teacher education.

Due to the afore-mentioned, we suggest that there should be different types of models for linking pre-service and in-service teacher education so that they could be implemented regardless of the connections between pre-service and in-service teacher education providers. These can take place with joint or parallel CPD for pre-service and in-service teachers (e.g. Asikainen & Hirvonen, 2009; Nivalainen, Asikainen; Sormunen, & Hirvonen, 2010) or with special teacher training in cooperation with in-service teachers for pre-service teachers, for instance. A special attention should be put on the transition period, during the first years of teaching *(see example from UK)* in order to support new teachers.

References:

Aksela, M. (2010). *Evidence-based teacher education: becoming a lifelong research-oriented chemistry teacher?* Chemistry Education and Practice, 11: 84-91. doi:10.1111/j.1949-8594.1999.tb17504.

Asikainen, M. A.& Hirvonen, P. E. (2009). *A study of pre- and in-service physics teachers' understanding of photoelectric phenomenon as part of the development of a research-based quantum physics course.* American Journal of Physics, 77: 658-666.

Nivalainen, N., Asikainen, M. A., Sormunen, K. & Hirvonen, P. E. (2010). *Pre-service and in-service teachers' challenges in the planning of practical work in physics.* Journal of Science Teacher Education, 21(4): 393-409.

In Austria, IMST thematic programs

Within the thematic programs of IMST, there is the possibility for pre-service teachers to work on an IMST project in their curricular praxis hours. These projects (approximately 5 per year) are accompanied by professionals from teacher colleges and the IMST scientific staff.

They routinely follow the iterative cycles of learning as proposed by the model of reflective practitioner. For example, in the school year 2017/18 pre-service teachers at a vocational school accompany their optometrist students in their final project of constructing a spectacle from scratch. As they follow an inquiry based learning approach in their teaching, it is key that they reflect their methods and interactions as well as their learning process with their guides at the teacher college and the IMST scientific staff. The IMST project report is the tool to document this processes. Furthermore, the final project report is handed in as the bachelor`s thesis at the teacher college. This combination of in-service and pre-service teacher education developed due to regional synergies in Innsbruck. In recent years, the vocational training schools in Tyrol carried out several innovative projects funded by IMST. Teachers at the program line for Photography, Optics and Hearing Acoustics for example already work with vocational students while they themselves finish their BA studies at the educational college. One IMST project, that accompanies BA students during their work as teachers, currently deals with the development of the often classically conducted, practical workshop classes. Until now, these classes are characterized by a traditional implementation of repetitive teaching methods that concentrate on a subject-related workpiece to be finished by the end of the school year. Unfortunately, these workpieces often only serve as preparation for the practical apprenticeship exam. This often leads to a loss of motivation among the students. Additionally, most teachers in vocational schools still teach the content in a teacher-centred style. However, the current changes in the Austrian curriculum call for a stronger pupil-centred education. The focus on students' competences therefore requires a reorganization of the teaching style towards, for example, cross-curricular teaching and participative teaching methods, such as Problem-Based-Learnings (PBL). One IMST project therefore focuses on PBL teaching methods and explores how they could be better implemented in the vocational training school setting. Through the combination of the restructuring of the lesson and the problem-based learning method, the teacher aims at motivating the students to acquire selected skills. A second goal of this IMST project is the integration of the wider teaching staff into these efforts.

Training schools (NEP)

One of the most positive experiences NaturErlebnisPark Science Education Centre has had is with the so called "visiting classes", where pre-service teachers practise classroom work under supervision of experienced teachers. This setting provides opportunities for different levels of CPD. With the supervising teachers, NEP develops framework programs for a school year. Pre-service teachers attend introducing workshops on IBSE. They develop short teaching sequences and test them in their visiting classes. All persons involved benefit. Pre-service teachers get authentic teaching experience with IBSE settings under guided conditions. Classroom teachers get new impulses. With the helping hands of the student-teachers, they have the opportunity to carry out complex and mentoring-intensive IBSE activities in a usual under-staffed classroom for these types of activities. Many of the participating pre-service teachers get the motivation to take part in IBSE projects in their later career as in-service teachers.

In UK, the vision of a Professional learning journey

Pre-service teacher Education within the UK is provided via predominately two routes- University based post-graduate courses or schools-based training. The university route has inputs on a wider range of topics, educational theory and subject knowledge, whereas the schools-based route has more classroom practice, but access to deeper pedagogy and theory may be limited.

Both routes provide a base understanding for teachers, but there are identified areas that are lacking in both. Support for wider subject knowledge (especially as teachers are often teaching out of specialism – such as a biologist expected to teach chemistry and physics to the age of 16) and good practical science is missing.

Over the last 10 years, we have strived to improve the link between pre-service and in-service CPD. This involves engaging with initial teacher training (ITT) providers- universities and the school-led routes- in order to support science teachers with both transition to their first teaching post, and to plan for CPD within their school over the first few years of their teaching career.

Engagement starts with planning with ITT providers- to enable trainee teachers to engage with the wide range of career-long support. This involves working with those who provide the CPD- so the National Science Learning Network, SSERC (Scotland) and the National STEM Learning Centre. Trainee teachers who are exposed to the opportunities and advice available at an early stage are much more likely to engage with subject-specific CPD throughout their career.

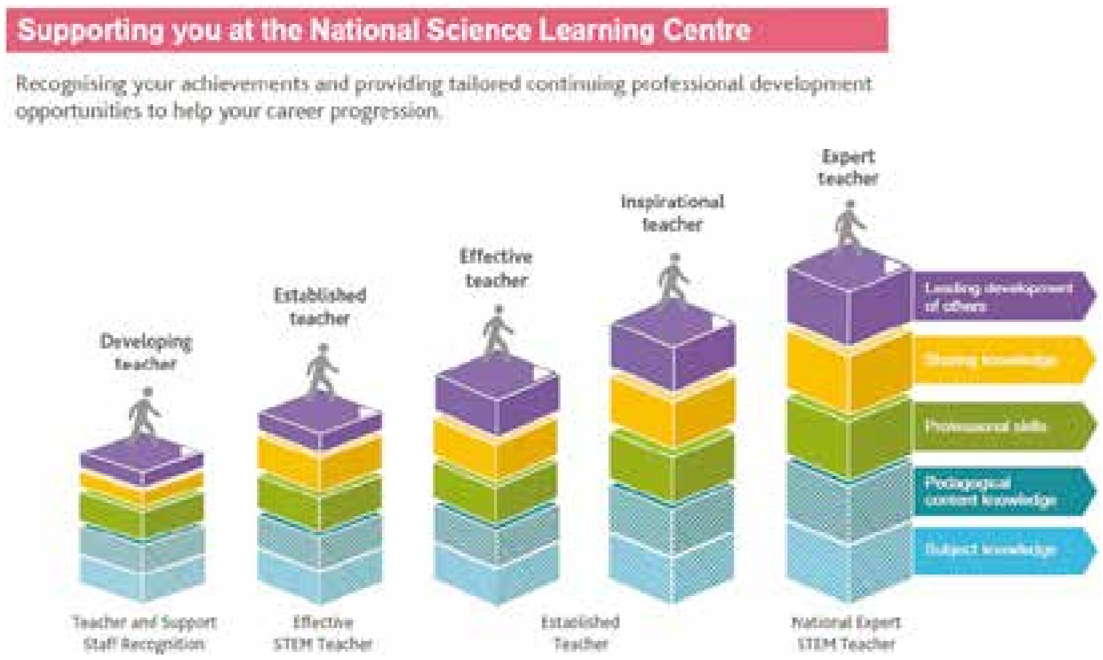


Fig. 6: The STEM Learning Professional Learning Journey; CPD for all teachers at every stage of their career

Summer schools covering practical science skills and subject knowledge help bridge the gap between pre-service training and the first career post. These invaluable intensive courses help those new to teaching develop and reflect on their current practice, as well as identify further areas for development.

Once in post, individuals and science departments within schools are provided with a tailored range of in-service CPD- immersive residentials, shorter episode face-to-face and online versions; giving a wide variety of options to suit teacher and school circumstances. Conferences for newly and recently qualified science teachers, at local and national level, enable science teachers to share good practice, network and further enhance their skill set.

The Professional learning journey as shown in the diagram below, maps the STEM Learning CPD offer so that there is a menu of support for teachers at every stage of their career.

3.3.2 Who shall conduct CPD for teachers?

Apart from educators, teachers' trainers, LINKS partners think other players should be involved in the CPD for teachers

In the process of developing IBSE among the teaching community, it has been obvious that such an approach would imply not only changes in content and pedagogy but also in the players who would be involved.

Apart from the pedagogical advisers, inspectors and other key persons within the educational system, other types of actors can play a role in teachers' professional development programmes. For many years, this has already been the case of science centres, museums, associations, and other types of non-formal education players that have been involved in fruitful cooperation of various types with teachers and schools.

Besides these players, LINKS partners have been developing other forms of involvement for individuals with specific skills mobilized for CPD purpose. Their experience has especially allowed the inclusion of **tertiary students and scientists** as effective contributors to CPD.

3.3.2.1 The possible role of students

A first group that can provide useful support for teachers, especially those who begin in IBSE and are lacking confidence in the discipline or the pedagogy, includes university students, either in science or in education, especially at master and PhD levels.

Science students are of particular interest for the provision of content-orientated support targeted at primary teachers (see the example in France). Such support is effective and reassuring for teachers during their first steps in IBSE, both for the preparation and the implementation of class sessions. The scientific topic is determined by the teacher and the accompanying student. The student particularly helps to identify important scientific knowledge, prepare and test beforehand the different types of experiments, models or observations that children may propose during their investigations.

Both distance and face-to-face support is possible. However, the most effective formula, at first, is where the scientific tutor attends all sessions in the classroom, working both with the teacher and children during a few weeks.

Of course, it is necessary to train or inform the scientific tutor on the expected accompaniment. To this purpose, common meetings with the teacher should be organised, preferably in the presence of a trainer to help clarify the role of each other.

As for students in education, they can be mobilised to support teachers in the field, especially through specific small-scale projects they design and implement with groups of teachers or schools in the frame of their research. The advantage of this type support is that such projects can be planned over 1 to 3 years and thus constitute an important asset to test innovative approaches.

It is essential to consider a proper incentive for the participation of students. Even for short-term activities, not pertaining to core course units of scientific students, awarding ECTS is the main and more effective solution.

In Finland, teacher students take informal PD to schools,

Educating forth-coming teachers in Finland takes place not only in subject departments but also in education departments. This example is from School of Applied Educational Science and Teacher Education of University of Eastern Finland. The university teachers mentioned here have background in both educational sciences and STEM subjects.

The underlying idea of taking informal PD to schools is that teacher students develop suitable projects and materials for certain themes (e.g. senses, energy production, and organic food vs. factory farming) and head to actual schools to implement these in cooperation with the school teachers. This is part of teacher students' compulsory education, and the development work is supervised and reviewed by teachers and fellow students. There are no explicit PD sessions given for teachers during these visits but they have to actively participate in implementing student projects which means that they learn by doing and seeing example from the teacher students.

Currently, this type of model takes place in two LUMA Finland Development programs which means that most STEM subjects are covered in this model. Besides, there are new projects starting that concentrate on widening the same model to ICT and modern learning environments. As this model has been proven to be a functional and good learning opportunity for both students and teachers, there has been discussion about extending this model to cover all teacher education programs nationwide, due to the two-way benefits.

In France, scientific students help primary teachers

In France, the programme named ASTEP, "supporting teachers through the involvement of scientists in primary education" was developed fifteen years ago. This programme aims to promote a system where researchers, engineers, technicians and mainly science students commit themselves to participate actively in supporting primary school teachers and their students. The scientific tutor commits him or herself to regularly come in the classroom, one half day per week, for a period of at least seven weeks between two school holidays in order to give continuity to his or her mission. The contribution of the scientist is resolutely part of an investigative approach. This cooperative work is beneficial for all the parties involved: students, teachers and scientists. They all discover a civic and formative project where all the fundamental aspects of the scientific approach are reinforced by the knowledge and experience of the scientist. For the teacher, this support is an opportunity to try a new professional approach and therefore a chance to view the science programme with less apprehension, to gain confidence in the implementation of scientific or technological methods and to consolidate mastery of course content to achieve autonomy.

3.3.2.2 The growing role of scientists

LINKS partners have taken numerous initiatives to build up viable structures for cooperation with scientists and scientific institutions who can play a very substantial role for the reinforcement of teachers' epistemic knowledge and attitudes and for the inclusion of real life science in the school. These scientists can come from public laboratories or companies, be technicians, engineers or researchers.

Indeed, the majority of teachers experienced traditional science education during their schooling and had little opportunity during their university curriculum to practice science in laboratories or companies – if ever science at all. This prevent them from understanding the importance of the scientific approach as an object of instruction and the indispensable link it constitutes with the professions related to science.

A wide range of possible involvement for scientists

Very diverse forms exist to involve scientists according to their competencies, will and availability: a first stage can consist of providing scientific support e.g. delivering a scientific conference during a training session or in the class to promote scientific subjects and careers.

Actually, several curricula require orientation to living conditions and emphasize career knowledge. To this purpose, personal contacts with role models have proven to be an effectual resource to overcome students' and teachers' reluctance to engage with science and technology (*see example from UK*). They produce a real change in awareness of science and other STEM subjects, as STEM careers. In fact, scientists and engineers share their passion and enthusiasm for a subject as well as their knowledge. This is inspiring for the teachers who can after that "bring to life" opportunities for young people. They are more able to share with students their improved understanding of the breadth and diversity of STEM careers and people working in STEM.

Such experience can be even more deepened through the development of placement programmes where teachers discover during a few weeks the context and activities of a company (*see example from Finland*).

Then, participating in CPD activities aiming is a second wide category of involvement including the development of the scientific culture of the teachers, the production of a pedagogical module (see example from Austria), or further integration of scientists e.g. as trainers in the teachers' professional development which is an advanced and challenging type of participation (*see examples from Italy and France)*.

The involvement of scientists in teachers' PD is effective…

Involving scientists at all stages of a training session, from its preparation to its implementation without forgetting its evaluation, has turned out to be quite relevant. It contributes to change teaching practices by giving teachers the opportunity to understand how science is built, to exchange with scientists on their research topic, on the issues addressed, on career paths and the work of the scientist on a daily basis. This is thus a very effective way to improve teachers' scientific knowledge, but not only. Studies show that the acquisition of new knowledge, skills and understanding are improved with the support and challenge from someone with expertise in the area.

Experts help participants to access new learning giving them new ideas, strategies and materials for delivering lessons in a more engaging and effective way. They also make teachers thinking about their existing practice in new ways.

The intervention in pairs, educator and scientist, favours a professional development using active methods, consistent with both IBSE and scientific approaches. Objectives related to a better understanding of science are even more easily achieved when part of the training takes place at science sites, in laboratories or in companies, at the very place where scientists involved as trainers work.

… When paying attention to some points

The presence of external experts, however, is not enough to guarantee success. To have a truly lasting effect, continuous professional development experiences must embed throughout cutting-edge subject, pedagogical knowledge, and understanding of teachers' needs. Experts need more than their knowledge; they also need to know how to make the content meaningful to teachers and manageable within the context of teaching practice. This is the role of CPD provider and trainers to guide the scientists in that way when they build their training contents. Forming pairs consisting of both a scientist and an educator specialist in IBSE is in this case highly advisable and mutual training times shall be arranged.

In this preparation process, educators shall also pay attention to the fact that scientists may also be influenced by their own school experience.

Moreover, they do not necessarily see the value of communicating about their professional approaches.

That is why, just like for students, it is important to consider the added-value for scientists and their employers to participate in CPD. Mainly, such players would seek for the individual and collective promotion of their skills and trades, values and social responsibility.

How to initiate a dialogue with scientists?

In some cases, first relations work on an informal level: scientists and teachers or trainers are personal acquaintances or scientists who are also parents of school kids. In those cases, the social fabrics within a municipality are a central factor of success. Usually, the participants in these collaborations share a strong commitment for education.

In other cases, accessing scientists is supported by local strategic management boards, universities, LINKS partners themselves, and in some cases funders. It has taken time to foster and develop such relationships with scientists who now take part in common activities with CPD providers. The focus on social responsibility for many universities and research organisations has certainly helped with this partnership and input.

Towards sustainable cooperation

A common trend within the LINKS partner networks is that scientific as well as business-partners work free of charge in educational projects. Their motivations are personal relations and/or they see benefits in disseminating knowledge about their research topic. However, the success of such projects depends on the relations and networks of educators. Therefore, the reach of these programs may be limited.

That is why the LINKS Network partners want to stress that the development of more sustainable cooperation structures requires more efforts.

One proven successful approach is the continuous cooperation between CPD coordinator institutions and umbrella organizations in science and economy (e.g. Academy of sciences, chamber of commerce, loose platforms of teacher trainers, schools, universities, scientists and enterprises). In this cooperation, the majority of work is done on a voluntary basis as well, but in many cases, resources like human resources, rooms or public relations structures of the partners are incorporated. Such permanent collaboration between structures makes it much easier to find appropriate cooperation partners for specific projects. In order to maintain such close contacts, it is necessary to entrust persons with the coordination. This can for instance work via service allocations for a few working hours of teachers or teacher trainers in the public service or of employees of the partners. In spite of successful voluntary collaborations, we have to state clearly that a substantial, intensive cooperation between CPD-, science- and economic structures call for adequate and secure financial resources and/or reliable frameworks. Among the LINKS partners, we found some approaches to institutionalize science-education cooperation:

- Systematic inclusion of cooperation activities into research proposals (relying on the dedication of a certain amount of the grants to outreach activities and participative research with schools)
- Specific grant programs of research promotion agencies under the condition of cooperation between schools, scientific and economic institutions
- Funding for intermediary structures (Science Centres, networks) that bridge science, educational and business organisations.

Regardless of the level and structure of cooperation, the experiences of the LINKS partners prove that not only schools and teachers benefit from such collaboration through reflecting and opening up scientific belief-systems. It is enterprises and scientists who gain a valuable asset while working with science communicators and translating scientific findings for different audiences without over-simplifying or falsifying their central message.

In UK, training STEM ambassadors as CPD facilitators

The Polar Explorer programme (PEP) using the theme of polar exploration encourages and supports schools who are keen to raise aspirations and attainment in STEM subjects and aims to inspire the next generation of scientists and engineers. The programme offers participating schools learning resources themed around polar exploration and engineering, teacher CPD and access to specially selected STEM professionals, known as Polar Ambassadors (PAs), who receive bespoke pre-project training on project resources/ activities and help schools to enrich the teaching of STEM subjects in primary schools.

This is the second programme which uses the model of STEM specialists as programme facilitators of CPD and STEM activities. The same approach was successfully trialled in the Tim Peake's Primary Project (2015-17), which used the British astronaut Tim Peake's mission to the International Space Station to promote space as a context for science learning in primary school. Evidence collected in both programmes shows that training STEM ambassadors to develop equally strong knowledge of industry context and educational environment significantly improves their effectiveness as STEM industry champions in schools. Their dual expertise in both fields of industry and education enable them to engage with teachers developing their confidence and teaching skills and with learners providing enthusing and impactful activities. Importantly, attending the school on multiple occasions gives SAs the opportunity to form an ongoing relationship with teachers and pupils. The results show an increase in the uptake, dissemination and embedding of enrichment activities.

In Finland, teachers benefit from placements in companies

One possible way to enhance teachers' know-how about scientific culture and working life is arranging systematic on-the-job learning for teachers. On-the-job learning can take place in diverse companies, and certain companies in Finland have already piloted this with a few teachers. Based on teachers' opinions and views, the teachers in Finland find this type of model interesting and useful for their profession, especially now that career knowledge and cooperation between companies is emphasized in the renewed national curriculum greatly. Due to this, it is important that teachers familiarise themselves with different companies around them and on-the-job learning provides a good way for achieving that

In this model teachers are expected to spend a couple of days or even a week in a company, follow the employers around, and get an idea of how the company works. If teachers know how the companies work, it will be easier for them to take their pupils and students to different companies and to introduce different types of possible job opportunities for them.

In Austria, monthly CPD is organized with scientists, researchers, teachers and economic operators

The "Talente regional" project funding of the Austrian Ministry for Traffic, Innovation and Technology supports initiatives that engage kids and young people to get in contact with authentic aspects of science, technology and innovation for a long period. Precondition for a project grant is, that at least five educational institutions of different levels (Preschool, primary education, secondary education), two research institutions and at least three economic enterprises form a consortium and that an intermediate institution coordinates the project.

"NaturErlebnisPark Science Education Centre" developed a format to incorporate CPD activities into the project: the "Permanent Science Breakfast" is a monthly dedicated day for the involved teachers, educational researchers, technical scientists, teacher trainers and economic operators as well as students of different fields of study (educational studies, technical studies). In a relaxed informal atmosphere, the partners present scientific facts, developments and literature concerning the project or they discuss their relevance for the project activities.

In a co-creative process all people involved create further activities for the classroom, taking into consideration scientific facts as well as educational knowledge. This way, content knowledge is immediately connected with adequate educational settings.

One example developed in the "Science Breakfast" setting is the activity "Play Science" where Playmobil® figures are used to initiate scientific dialogues with pre-school kids.

In Italy, the role of scientists in providing support to educators

The role of scientists has evolved along the years according with a synergic and systemic vision that is quite challenging in Italy for stereotyped cooperation in Education. The cooperation with scientists-members of the Accademia Nazionale dei Lincei implemented in the framework of the SID (Scientiam Inquirendo Discere) project, has been pivotal for a more closely, well-organized and wide range cooperation with the scientific community. Local academies connected to the National Accademia and ANISN sections are spanned in all Italian regions. Along the years, this cooperation has been developed in different forms in the IBSE local centres. Some centres are based also at Academies or Universities. The general architecture of SID project has been adopted by the Accademia dei lincei to set up a bigger Educational project "I lincei e la nuova didattica" focused also on maths and Italian language with hundreds of academicians actively involved to date.

Many scientists, apart from the ones involved in SID project, actively cooperate to organise training courses in IBSE centres. Different forms of cooperation have been developed: seminars on cutting-edge science topics by scientists followed by sessions organised by ANISN trainers to present (or to involve trainees in active sessions) examples of didactic transposition of the core ideas of the seminar in the classroom; co-planning of training courses to deepen some scientific aspects; working groups with ANISN trainers to develop new educational resources; participation to residential summer schools. This synergy between scientists and educators has been existing for many years and has represented a successful evolution in Italy as a strategy to capitalise joint efforts for STEM education avoiding the usual dispersion.

In France, scientists and educators design and conduct CPD sessions together

To develop a common scientific culture, it is essential that the teachers can discover the sciences and their production under various aspects: knowledge, scientific approach, links with society…

For that purpose, one of method which we use is to organize CPD training sessions) in laboratories, or in companies, or in structures of scientific culture. In those places, the teachers can meet scientists, engineers and or popularisers, and get a better understanding of how science is produced, used or transferred.

An example of CPD training session based on that concept is "meteorology and global warming" organised in partnership with the CNES (Centre National d'Etudes Spatiales – National Center for Space Study) Météo France (French Weather Agency). This action takes place in la Cité de l'espace, a museum dedicated to sky and space sciences.

During which the teachers:

- Update their knowledge on the theme of climate and spatial imaging technics thanks to the intervention of researchers and engineers of the CNES,
- Exchange with engineers of Météo France (who lead a corner with experimental modules within the museum) on techniques used in meteorology,
- Then discover the resources of the place accompanied with mediators, allowing them to envisage activities in classes, or educational visit as a supplement to the course.

3.4 What are the conditions for successful CPD programmes?

LINKS partners are part of an organisational environment made of the educational system itself with all its political, administrative and operational components, and of other institutions, both public and private. If the enhancement of STEM education through CPD is a shared aim for all these players, their strategies and expectations may differ while it is necessary to rely on a common framework to ensure greater cohesiveness and efficacy.

LINKS partners are very committed in contributing to the design of such a **common strategic framework** in their respective countries. To this purpose they are well aware that decision-makers need *first* to support their choices with sound analysis of data, hence the large efforts that have been made to develop **strong quality-assurance processes** in all countries.

However, taking into account the environment shall not be limited to the institutional approach only. Ways to improve the response and commitment of individual teachers to CPD opportunities shall also be worked out. If the motivation may already be improved by a better consideration for teachers' needs (in the quality-assurance process), another key element that has been explored by LINKS partners in collaboration with Universities is to offer more recognition to CPD in teachers' education, a first step that should be furthered by public authorities in terms of career management for instance.

3.4.1 A strong quality-assurance process from the assessment of teachers' needs to the evaluation of the impact of CPD

If the organisational environment of CPD is important, it should also not be forgot that teachers, individually, remain at the heart of the success of any programme; that is why quality-assurance shall not only address the results and impact of CPD in relation with institutions' expectations but first of all the needs expressed by teachers themselves.

3.4.1.1. Assessment of teachers' needs

Self-Determination Strengthens Learning Environments

When it comes to teachers' needs, self-determination theory postulates that there are three basic psychological needs in addition to the biological-physiological needs of a person (for example, the need for food). These are the need for autonomy, competence and social inclusion. Autonomy in this context does not mean independence from external influences, but refers to the need of people to perceive themselves as the sole cause of an action or to pursue a self-chosen goal. When it comes to the need for competence, the desire for the feeling of effectiveness and self-efficacy during a specific (learning) action is at the centre. The need for social inclusion expresses the desire of people to be in contact with (important) others, to feel a sense of attachment, and to be part of a community that accepts them (Ryan & Deci, 2002, 2005). The social environment of a person needs to support these needs for self-determined motivation to develop. When it comes to teaching, evaluation proves that "teachers can serve as role models for students. Pupils are immediately enthused when they realize their teacher's own interest in the subject matter" (Müller, Andreitz & Fussi, 2009).

Teachers' Needs: Evidence and Process based CPD

In the United Kingdom, but also in Austria and Finland, the last decade saw the introduction of ideas of New Public Management. Around these, some elements of evidence-based control have been developed to guide the scope and development of (intermediary) structures. These include instruments for the measurement of real achievements within programs the partners carried out. In addition, the data gathered should also indicate needs of participating educators. Along with evidence based efforts there is a shared viewpoint that CPD programmes cannot offer blueprint solutions for all schools and educators engaging in further education. Moreover, it is key to analyse and reflect the circumstances of specific educational settings before developing CPD contents and processes. We are very well aware of varying needs and time capacities of pupils and teachers.

Within the LINKS partnership, we follow these approaches and ways of measurement to ensure the consideration of teachers' needs:

a. Approaches that aim at the professionalization of practices in close connection with teachers' autonomy, competence and social inclusion: These include: introducing and practicing action research, lesson studies, and inquiry-based learning approaches within teaching communities. We favour them because of their inbuilt close feedback methods. Propagating the use of formal and informal learning environments, out-of-class learning in non-formal settings and collaboration across school subjects to widen the scope and techniques of knowledge acquisition. Teachers and teacher trainers design CPD courses together.

b. Approaches enhancing action and reflection of everyday interaction to propel self-motivational learning processes: These include feedback on work in practice within peer groups in day-to-day activities, lesson observations, steering group meetings on subject matter didactics within schools, communication of performance results or actual target discrepancies of regional/federal authorities to schools in a region. This data feedback is intended to stimulate and control activities to improve the system. These measures go hand in hand with support tools to increase the effectiveness of evidence-based proceedings. These include, for example, handouts of competency-based task examples, diagnostic informal competency measurements (IKM).
c. Use and dissemination of methods of feedback and impact measurement: Feedback within program offerings like interviewing teachers and students at the end of the program, and again a few weeks thereafter. Used tools are e.g. CPD surveys completed during residential CPD where participants are asked 'What are the next steps of your professional learning journey?' This informs the mapping of relevant CPD for each participant at each stage of their career or particular area of development. Another example is distributing electronic forms before a CPD starts to inquire beforehand knowledge on a specific subject matter and responding teachers' needs.
d. Accumulation of information on current and future trends within STEM learning: Analysis of current research and liaisons with national expert teams on subject matter education that deliver CPD in residential programs. Considering funder priorities in the design of new programs e.g. Ministry of Education, association of business entrepreneurs, Academies of science, etc., considering competitor offers, conference attendance and general horizon scanning. The collection and analysis of recruitment numbers for courses over the years and tailoring future program offer.

Overall, the LINKS partnership recommends a broad variety of measurement to consider and combine teachers' needs for the development of motivational STEM teaching and learning environments.

References:

Müller, F. H, Andreitz, I. & Fussi, A. (2009). *Motivationsförderung im Unterricht: Zwischen Utopie und Machbarem*. In K. Krainer, B. Hanfstingl & S. Zehetmeier (Hrsg.), Fragen zur Schule – Antworten aus Theorie und Praxis (S. 31-49). Innsbruck: Studienverlag.

Ryan, R. M. & Deci, E. L. (2002). *An Overview of Self-Determination Theory: An Organismic Dialectical Perspective*. In R. M. Ryan & E. L. Deci (Eds.), Handbook of Self-Determination Research (pp. 3-33). Rochester: The University of Rochester Press.

United Nations Sustainable Development Goals (2015). A/70/472/Add.8 - *United Nations Decade of Education for Sustainable Development*: Report of the Second Committee.

In Finland, identifying teachers' expectations to prepare training sessions

LUMA Centre Finland carries out CPD training supporting the objectives from the renewed national curriculum and based on the latest research findings. In Finland, most CPD education sessions are planned and organized together with teachers and teacher educators; the objectives of the sessions are typically based on the needs of the teachers participating in the training.

University of Helsinki Science Education Centre will arrange a CPD session concerning the utilization of school science laboratories in formal school learning in the spring of 2018. An electronic form has been shared with teachers so that they can tell what kind of education they would like to have concerning the use of school science laboratories. Below, some examples about the questions from the electronic form are presented:

- Do you know what school science laboratories are?
- What kind of experiments would you like to do in a school science laboratory with your pupils?
- Do you already have an idea of some particular experiment you would like to test in a school science laboratory?

The responses for these items will provide a starting point for designing this CPD session; the aim is to answer for teachers' needs with research-based education sessions.

In UK, identifying needs from the individual to the systemic level

At individual level, every teacher and technician who participates in STEM Learning CPD is asked to complete a pre CPD survey (part of the Impact Toolkit ITK), which identifies any specific misconceptions or particular support they may require in relation to subject knowledge or pedagogical approach. This enables the CPD facilitator to design and scaffold the CPD to address the needs of each individual teacher. It also identifies the stage of the teacher in their professional career so that the appropriate pitch and level of challenge is planned for.

At national level, Enthuse funded CPD is designed and scheduled on a termly basis. To ensure consistency across all programmes, subject expert workshops are held to share the current educational priorities for science, design and technology, engineering, maths and computing for each stage i.e. early years, primary, secondary and further education. This enables cross curricular links and themes to be identified, especially in leadership and current evidence based pedagogy – as well as providing the overall picture of the STEM educational landscape and associated priorities. The outcomes are then communicated across the Network through super regional and Network leadership meetings.

Each STEM programme compiles a needs analysis evidence base, which is a working document. Programme leads continually collate information to populate the evidence base and to inform the next stage of the programme planning.

3.4.1.2 Evaluation of CPD outcomes

Evaluation and impact measurement are important aspects of any educational intervention, including professional learning of teachers. Evaluating the impact of CPD can be challenging, especially when assessing effects that go beyond the direct impact on teachers, such as changes in students' attitudes, attainment and progress, or longer-term changes in the school or department. Whilst acknowledging such challenges, it is our experience that the impact of professional development can be planned and evaluated meaningfully. As we discussed a spectrum of possible approaches within our partnership, we suggest drawing from a wide variety of methodologies and methods.

During our LINKS twinning meetings we established that all project partners use evaluation to assess CPD activities, with the objective of assessing to which extent they answer to the expected needs of teachers and to our goal of changing the pedagogical practices. The aim is for us all to be better informed and able to improve our CPD.

Yet the standards and practices are far from being uniform. Largely this diversity is explained by differences in national educational contexts and standards. Although in most European countries there is an expectation that CPD providers should use some form of evaluation, very rarely there is a clearly defined requirement for in-built quality assurance process, structured formative evaluation or rigorous impact analysis. Equally uncommon is for CPD evaluation to require evidence of impact on students. Only in a minority of countries, like UK, where there is a national system for collecting student and school performance data, there is a large-scale drive towards measuring effectiveness and impact of CPD by its impact on student outcomes. In particular, the focus on students as the main criterion of good CPD is stipulated in the UK national Standard for teachers' professional development (Department for Education 2016), which also expects teachers involved in professional learning to develop reflective and evaluative skills so that they can critically assess the impact of their innovative practices. Doing evaluative research on impact of CPDs within educational settings, we need to state that the input-output relation is **not** a trivial one. Contexts (educational systems, organisational structures, personal involvements, motivations, preconditions, etc.) largely influence the scope and the effects of our work.

This approach to professional learning is based on international research and best practice of what works in CPD. It suggests that effective CPD has to support evidence-informed practice of teachers and that ability to evaluate one's own learning and teaching is an important element of this approach. For CPD to be effective in improving quality of teaching and raising outcomes for students it has to include impact planning and measurement at all stages of the process. This approach helps to optimise teacher professional learning, embed positive changes in their professional practice, maximize benefits for students and disseminate good practice across the teaching community.

Within the LINKS partnership we share the vision that CPD should help teachers develop reflective skills and make them active contributors to evaluation rather than passive objects of external evaluation. To this purpose, teachers should be provided with a set of bespoke evaluation tools and/or tools for reflective practice (e.g. Impact toolkit, self-reflexion tool kit, PAR approaches), which are blended into the programme delivery process, helping capture key aspects of their professional learning journey as well as plan, implement and evidence post-CPD interventions. This process of embedding evaluation and reflective practices into CPD also supports its quality assurance and guarantees high standards in formative and summative evaluation.

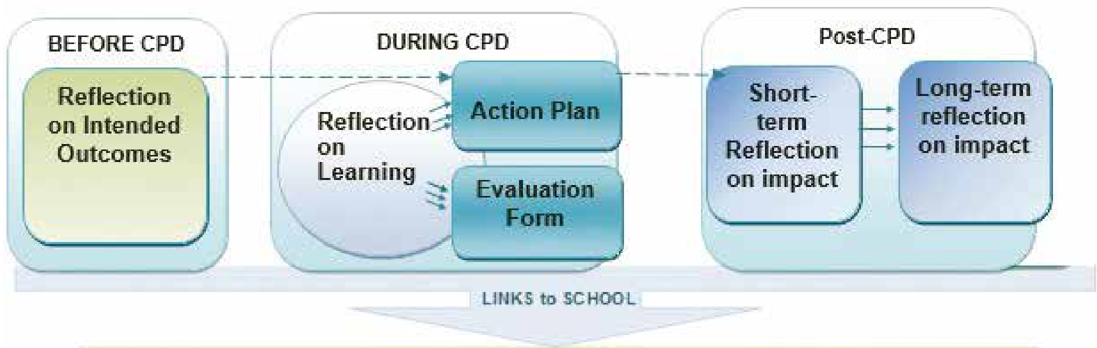


Fig.7: An example of embedding evaluation in CPD

Among the LINKS partners there are some excellent examples of how embedding evaluation in CPD gives teachers active ownership of their professional learning and ways to measure its impact on themselves, their colleagues, students and schools. This Impact toolkit can be used by all CPD participants (teachers, technicians and other education staff) and consists of a collection of forms, which participants complete before, during and after CPD.

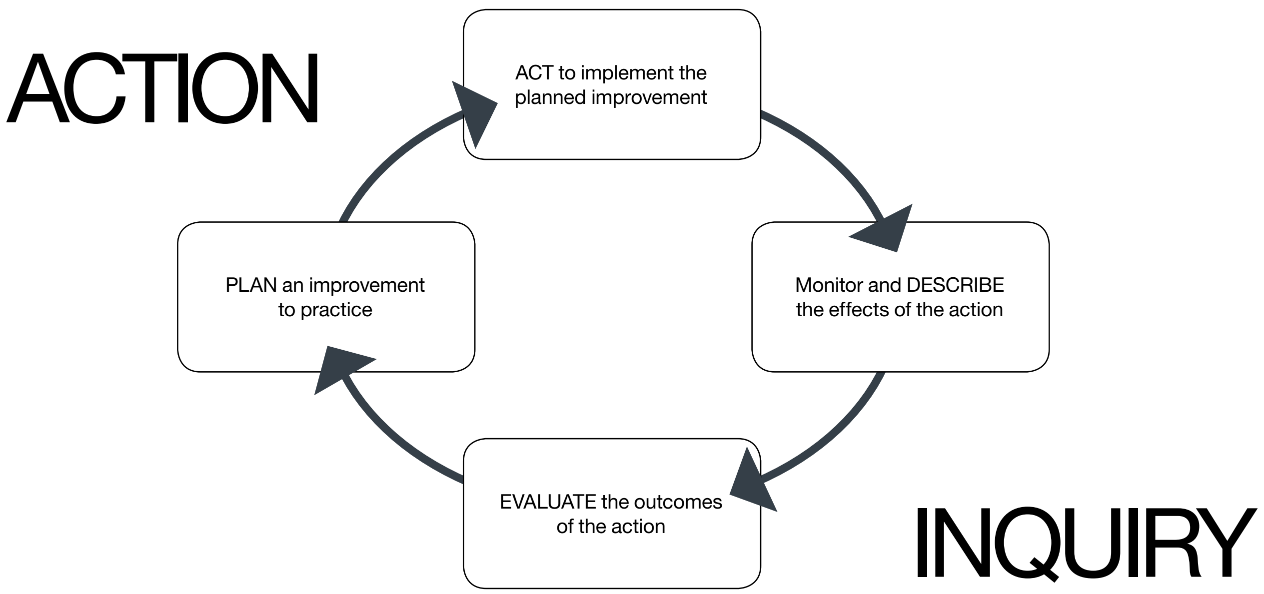
To assist CPD participants with planning and evidencing CPD impact, Impact toolkit should encourage them to reflect on their current practice and expected outcomes before CPD, reflection on CPD learning and action planning immediately after CPD and reflection on impact after CPD. It also has to give a structured guidance on possible impact categories in relation to the outcomes for participants, their students, their colleagues and schools. Teachers also need more help with defining so-called 'success criteria', i.e. their bespoke measures of impact, as well as with gathering and assessing evidence to use in evaluation.

In designing the method of impact evaluation, we also rely on Guskey (2000) model of evaluation of CPD which recognizes that different CPD outcomes take different times to occur, hence self-evaluation needs to be collected at multiple points: immediately after an event, 6-8 weeks later and 6-9 months. After sharing best practice within the LINKS partnership we learned that effective impact-reporting tool should address the following categories:

- Achievement of planned outcomes and action points
- Evidence of impact: strength and details of impact on self, students, colleagues, school and overall
- Reflection on Learning
- Sharing of CPD

This clear, straightforward process makes capturing the impact of CPD by internal evaluation seamless and effective. It also benefits external evaluators, who provide independent assessment of the quality and impact. Involving teachers in self-evaluation makes them more appreciative of the value of evaluation, hence more willing to engage with external evaluators and more able to supply them with high-quality evidence.

Fig. 8: Iterative cycle for the reflective practitioner



In Austria, a meta-framework to guide all evaluation activities

The IMST project developed a system of external and internal evaluations at whole-project level and all sub-projects (Krainer et al. 2013). Thus, the specific interests of researchers and needed knowledge for further developing the corresponding subproject is balanced. An overarching theoretical framework has been developed for IMST along these pillars:

- Development of a Logical Framework Matrix together with the Austrian ministry of education, monitoring the progress of the IMST network
- Yearly activity reports
- Three-yearly final reports with quantitative and qualitative data analyses of the effects IMST contributed to
- Cross-case analyses of the regional networks
- Cross-case analyses of all school projects within the thematic programmes. The effect on teachers as well as on motivational aspects of students is measured. Additionally, all participating teachers undergo a process of becoming reflective practitioners as iterative PAR cycles are implemented within the IMST thematic programme.

However, this can be regarded as a kind of meta-framework which needs to be concretized when coming to a specific sub-project. The research projects are diverse in nature (e.g. focusing on students, teachers, school development) and build on their own research questions (e.g. focusing on mathematics teaching, other subjects, general pedagogical issues) and methodologies (e.g. qualitative, quantitative, action research). However, from the very beginning, teachers were supported in establishing an inquiry stance. IMST tried to engage other stakeholders (e.g. educational administration and policy) to take part in inquiry-based reflections on the project's challenges and outcomes. Therefore, IBL was no longer regarded as being confined to students only, but extended to teachers and to the whole educational system, assuming that in particular teachers with an innovation and inquiry stance are more likely to promote students' inquiry based learning competences. All in all, this means that the IMST project is different to most research projects (related to IBL) since it (a) is primarily an intervention project (having a specific focus on practice- and policy-relevant issues and results), (b) turned out to become a long-term project with a variety of goals and sub-projects, (c) emphasizes large-scale effects (e.g. on the level of students, teachers, infrastructure), (d) is carried out in collaboration with and primarily funded by several ministries and other stakeholders, thus having discontinuity and flexible dynamic adaptions as inherent characteristics, and (e) focuses primarily on teachers' learning, giving them the autonomy to define their starting points for innovation and inquiry themselves (Krainer /Zehetmeier 2013:4).

For further information, see the articles.

Krainer, K., Dörfler, W., Jungwirth, H., Kühnelt, H., Rauch, F. & Stern, T. (Hrsg.) (2002).

Lernen im Aufbruch: Mathematik und Naturwissenschaften. Pilotprojekt IMST². Innsbruck: Studienverlag.

Krainer, K. (2003). *Interventionsstrategien. Auf dem Weg zu einer „kooperativen Interventionsforschung“*. In: P. Heintel, L. Krainer & I. Paul-Horn (Hrsg.). WBI Klagenfurter Beiträge zur Interventionsforschung, Band 2. (S. 43-66). Klagenfurt, IFF.

Krainer, K., Hanfstingl, B. & Zehetmeier, S. (Hrsg.) (2009). *Fragen zur Schule – Antworten aus Theorie und Praxis.* Ergebnisse aus dem Projekt IMST. Innsbruck: Studienverlag.

Krainer, K., Zehetmeier, S. (2013): *Inquiry-based learning for students, teachers, researchers, and representatives of educational administration and policy: reflections on a nation-wide initiative fostering educational innovations*, ZMD Mathematics Education, FIZ Karlsruhe, DOI 10.1007/s11858-013-0537-z

Rauch, F. (2013): *Regional networks in education. A case study of an Austrian project.* In: Cambridge Journal of Education, Vol. 43, Nr. 3, 313-324, Routledge.

Zehetmeier, S., Andreitz, I., Erlacher, W. & Rauch, F. (2015). *Researching the impact of teacher professional development programmes based on action research, constructivism, and systems theory.* Educational Action Research, 1–16.

In Finland, a diversity of evaluation processes complements nation-wide evaluation

The biggest nation-wide evaluation concerning the programme is coordinated by University of Helsinki. This evaluation addresses the statistics related to the numbers of teachers and pupils reached but also teachers' view and opinions about the materials, CPD sessions, and their applicability in classrooms. These are evaluated with the aid of online surveys, personal communications, and informal feedback. As the programme is currently on distribution state, the evaluations taking place are on piloting phase and do not yet cover all teachers and pupils reached. Later, the evaluation will be conducted for all sub-projects and teachers and pupils that have participated in these.

Regarding individual sub-projects, most developers and educators have gathered various types of data (e.g. Likert-scale questionnaires, open-ended questions, interviews, etc.) during the development and distribution phases, and this evaluation has guided the development of the sub-projects furthermore. Besides developing the sub-projects, this data is to support research purposes, and hence there are no strict national guidelines for gathering this supplementary data, as all projects have their own special features. Besides, all developers have evaluated materials and activities of two other sub-projects to supplement this wide-ranging evaluation with peer evaluation.

For instance, Chemistry Education Unit in University of Helsinki has arranged a formative assessment CPD-training for teachers after the Finnish national curriculum has been reformed and the new curriculum emphasizes versatility in assessment in teaching in comparison to the previous national curricula. In this CPD, the teachers study formative assessment methods in small groups and try implementing those with the other groups. After this piloting phase, teachers choose the best methods for formative assessment and utilise those in their own classrooms.

In their classrooms the teachers are expected to choose a subject and a context, for example chemical bonding, and they apply their formative assessment methods in that context, preferably with the aid of IBSE. The teachers also collect data from these trials as they are expected to make some small-scale research related to that. At the end, teachers should have better readiness for versatile assessment methods that can be implemented with various teaching approaches.

In Italy, a systemic evaluation on its way

The evaluation of the CPD outcomes is based on the analysis of data collected in different time span with different purposes. The different centres are involved in different Italian or European projects, even if each one has its specificity and aims, the data and evidences gathered through on line surveys, in presence questionnaires, interviews, analysis of teachers' reports, etc. sustain the positive outcomes of different but interconnected CPD processes.

The impact of the key strategies adopted by all the centres are also supported by the everlasting or increasing commitment of all the actors; the scaling up process with a growing number of schools, teachers and students involved as well as the spreading at regional levels of the bigger centres through satellites centres; the vivid interest of the trainees and the numerous requests by teachers (and schools) to attend our courses that could not be accepted to assure their adequate quality; the advancement of the skills and competences of the trainees which become along the years able to act as "multipliers" within their school and in the schools' network; the enhancement of the expertise of the trainers which allows managing the complexity of the multilevel offer of PD courses. There is not a systemic evaluation to date, but multiple outcomes gathered in different time and ways. Some schools are involved in external evaluation by dedicated groups work belonging to the National Evaluation System (INVALSI) and great appreciation of the PD courses led by the ANISN IBSE network comes from these groups. A more specific systemic external evaluation on the strategies and processes adopted by the centres have been conducted in 2014 on 6 IBSE centres. The evaluation was focused on the Relevance, Efficiency, Effectiveness, Impact and Sustainability using face-to-face meetings and on-line questionnaires on different aspects of the PD courses (see appendix for data). The results were very positive and useful, allowing us to highlight the strengths and weaknesses to be aware in working forward. In the framework of School for Inquiry project started in September 2017 a systemic evaluation of the CPD in all the centres have to be provided by the end of 2019. We are confident to be able to collect more useful data and evidences by this evaluation.

3.4.2 CPD policy, strategic framework at national level

In general, the greatest influencers for STEM CPD policy are the ministries of education. Their role for CPD policy is versatile, and practically only with their support are nation-wide models for providing CPD possible. This steering is implemented by means of curricula and other standards for teaching (e.g. Opetushallitus, 2014), funding opportunities and decisions (see examples below), and other decisions impacting the requirements set for teachers and their CPD.

Another important quarter steering CPD policy are universities, even if the role and connection of them for STEM networks depend on the nation; for example, LUMA Centre Finland works under jurisdiction of local universities whilst STEM Learning in UK is an independent organization. This means that in some countries, CPD policy and strategies have to be in unison with university strategies. Besides, in some countries, it is essential to follow the guidelines and hierarchical structures emerging from the providers of education, including headmasters and inspectors, for instance.

That being said, it is essential that STEM CPD providers have their own nation-wide strategies that follow the guidelines and requirements set by the aforementioned quarters and simultaneously support and enable their own visions and aims. Depending on the nation, this strategy might give varying level of freedom for the actual CPD providers.

Generally, strategic frameworks seem to support the idea of having a guided network with local centres. Each local centre might provide both nation-wide and local CPD depending on the needs of teachers and focuses of those centres. However, it is strongly recommended that all activities can be provided nation-wide via CPD providers, as this element in a strategy does not only contribute to better geographical coverage but also treats teachers fairly. Another essential pragmatic element in the strategies is that CPD should not be provided solely by the primary actors but there should be training of trainers and other forms of spreading the message furthermore, such as MOOCs, included in the activities.

The most important factor contributing for CPD strategies comes from schools. Our mutual aim is to offer teachers and other personnel chances for functional CPD, and at the end it is teachers' expertise that we have to rely on whilst creating our strategies that steer designing CPDs furthermore. Thus, a functional feedback system is amongst the key factors contributing to our strategies as no strategies function unless teachers are willing to "buy" it.

References:

Opetushallitus. (2014). *Perusopetuksen Opetussuunnitelman Perusteet 2014* [National Core Curriculum for Basic Education 2014]. Helsinki: Next Print Oy.

In Austria, IMST and NEP play an intermediary role

IMST is one of the main programs of the Austrian ministry of education. However, budget cuts within the last years reduced its possibilities of impact. Due to the changed financial situation, a smaller number of schools are granted the possibility of participating within the thematic programmes (60 programmes a year). Nevertheless, results of the last evaluation prove that the intermediary structure shows some significant effects when it comes to achievement of long term goals in enhancing (regional and federal) network structures all over Austria and fostering a culture of innovation through thematic programmes.

Furthermore, IMST engages in national as well as international CPD initiatives through projects like Fibonacci, ARTISTS, PARRISE etc.). IMST is Part of the Science Centre Network.

NaturErlebnisPark – Science Education Centre has been involved in several national and international projects for scientific education (e.g. the Austrian IMST-program, Fibonacci, Grundtvig) and has been conducting various projects to develop and research innovative educational settings for science teaching and fostering interest in science and technology since 1997. The institution is part of the national Science Centre Network and focusses on the cooperation between formal and informal learning as well as on the training of explainers and of teachers. Primarily NaturErlebnisPark Science Education Centre influences STEM CPD on a regional level. Beyond that our concepts and findings expand into broader CPD communities via national and international networks and projects.

IMST as well as SEC see themselves as non-formal science learning structures and in their scope of work as intermediary structures.

In Italy, a recognition of the Ministry of Education

ANISN is a recognized Italian association both as qualified institution for the training of teachers authorized to set up institutional training courses for science teachers and as a Ministry of Education, University and Research (MIUR) external entity able to organize and conduct initiatives for the identification and promotion of excellence in Italian schools. Since its foundation it has worked in line with the National policy of the Ministry of Education aiming to improve and support continuously the quality and dissemination of STEM education in Italy, with the awareness of the crucial role that teachers and science teaching in school play in scientific culture and in the process of development of the students as science active citizens.

The cooperation with Ministry of Education is constant since its foundation and has been developed in different forms: as consultant to design the National Science curriculum; as member in National steering committee of the main CPD programmes led by MIUR; as partners since several years in CPD project led by MIUR and INDIRE (National Institute for Documentation, Innovation and Educational Research). MIUR supports ANISN action in PD in several ways: ANISN CPD courses are admitted to be published on the National platform of MIUR and this is a quality guarantee for the teachers; peripheral bodies of MIUR are involved in different forms in supporting the local centres (agreement among the local centre and schools network; support in the dissemination, support in the selection of attending teachers; support in financing schools' project based coherent with the CPD of the local centre). A specific agreement has been signed recently with the Ministry of Education to support the ANISN IBSE network through the School for Inquiry project funding system CPD actions in the 10 centres strengthening the cooperation with research institutions and International CPD provider.

ANISN has been partners in many educational projects in its long story, but in the last ten years more focused International partnerships to improve IBSE in Italy has been developed through many projects: Fibonacci, SUSTAIN, AMGEN Teach, Ark of Inquiry, AMGEN BIOTECH EXPERIENCE (http://abe.anisn.it/en/).

In France, a strong partnership with the Ministry of Education at all levels

From the very beginning of its action, and in relation with the various networks it has created, La main à la pâte has been seeking to be in line with the national policy of the Ministry of education. It has succeeded in developing and maintaining the role of an experimental independent player whose innovative initiatives would be tried out then embedded in the general framework of the public educational system.

This strategy meant to contribute to the development of the national policy actually mainly relies on a bottom-up approach taking roots in regional and even more local programmes implemented through the networks. In the case of the Houses for science, their creation implies a strong partnership between the Rectorat, in charge of the regional adaptation of the national professional development policy, the scientific university and the Foundation La main à la pâte. The Houses offer practical frames to develop a multi-stakeholder approach, adapted to the needs and opportunities of each region, a level which is in France crucial both in terms of policy-making and operational implementation for all public policies.

The various experiences of the Houses –collected, analysed and capitalised- are promoted as prototypes for more effective and efficient patterns of professional development. The aim is both to expand to other regions (horizontal dissemination) and feed the national reflection at the Ministry level where the national policy and training plan are framed (vertical dissemination).

In Finland, the national policy delegates CPD to LUMA for the years 2017-2020

LUMA Centre Finland with its activities, including CPD, has received funding and official status of implementing national task from Ministry of Education and Culture starting in the year 2017. This means that the value of the network and the education provided is acknowledged nationwide by authorities which indicates that the network and related activities are established in Finland. As one of the most essential, LUMA activities is supporting teachers' CPD by means of education and novel research-based materials, CPD can be stated to have a sustainable base in Finland.

The material and education development phase of LUMA Finland Development Programme projects is finished, and hence the material developers can currently concentrate on distributing the materials and educating teachers across Finland, both with face-to-face teaching and with the aid of distance-learning tools. As the programme continues for the following years and universities are engaged to the activities and there are new funding opportunities opening, the sustainability of bringing research-based tested CPD for science and mathematics teachers is assured for the present.

3.4.3 Certification of PD

The professional development certification includes aspects concerning both the acknowledgment awarded to the trainees (teachers and support staff) and the accreditation of professional development providers and their training actions. In both cases, it involves the recognition of the offered or attended training activities based on pre-established requirements.

In this sense, certification has a twofold function: on the one hand, it ensures reputation for professional development providers and visibility for their training actions, and on the other hand, it allows to show any training activity completed by the teachers, along with the knowledge and skills they developed, making all credits gained transparent and transferable. Independently of the involved level (trainers or teachers), the certification of professional development entails the acknowledgment of the efforts and commitment of the involved subjects. This starts up a process for the quality improvement of the training actions and of the professional development of teachers, with positive impacts for all the different components of school communities.

A certification of the teachers may also motivate them to follow more training sessions in science, involve them in a long-term process, to improve their knowledge and skills.

In various European contexts, different forms of recognition for professional development participants have been adopted. One of the most common recognition is the certificate of attendance delivered from the professional development provider. This kind of certification is very useful for teachers in order to update their curriculum vitae and it is needful in those countries where teachers' continuous professional development is compulsory. In some European contexts, other forms of public recognition have been introduced, which are characterized by a greater visibility. For example, there is the establishment of awards designed to recognise teachers who developed knowledge and skills in STEM through professional learning, and produced evidence on the positive effects on their students and colleagues. A similar form of recognition is the "Science Quality Mark" which has been introduced in some countries to recognise and celebrate inspiring practice within science departments.

Regarding the certification granted to the professional development actions one of the most common recognition adopted in different European contexts is the validation provided by the National Ministry of Education. This allows the inclusion of the validated proposals within the plan designed by regional or local districts.

Experiences of cooperation with University have led to the inclusion of some professional development in higher education Master's curriculum targeted at in-service teachers or trainers. In these cases the participants receive a recognition provided by the University based on the European Credits System (ECTS).

In France, providing an official IBSE course for trainee teachers

Certification within the network of the Houses for science is not addressed in a single, similar way.

The most common recognition, granted to the huge majority of the professional development actions, is their inclusion in the official PD plan of the region, validated by the Ministry of education.

However, further forms of certification are sought and do already exist, depending on the negotiation with the university in each House for science.

For example, in Centre-Val de Loire region, a cooperation has been launched with the local ESPE (college for teachers' training) in the frame of the Master 1 MEEF PIF (teaching, education and training professions – training design and practices), targeted at in-service trainers and teachers, especially those who do not hold a master yet. The House for science provides the option « Experimenting science to teach it » in the curriculum of this master. This option aims at developing the autonomy of teachers in IBSE. The objectives of the course are:

- to explore and reinforce scientific knowledge concerning a range of issues related to the new curricula, addressing them in an interdisciplinary way;
- to progress in the implementation of inquiry-based science lessons;
- to get familiar with co-building and co-intervention principles such as working with a student providing scientific support at primary level or working with a colleague at secondary level;
- to be able to analyse one's own practices and that of one's peers.

The House for science provides in this 2-semester course 52 hours of blended professional development allowing trainees to go through a diversity of inquiry forms with a focus on interdisciplinarity. In-between the various face-to-face sessions, trainees have to implement some activities with the pupils in class and share their experience with others to analyse their practices. The course also provides opportunities to actively interact with scientists and educators from the House for science.

This course, as an official component of the master, is validated by some ECTS.

In Austria, "Pedagogy and Teaching Didactics for Teachers" (PFL in German)

The PFL Programme has been offered since 1982 at the Institute for Teaching and School Development of the University of Klagenfurt (in recent years in cooperation with colleges of education) for teachers of several subjects and all types of schools. Building on PFL, the professional training course (ProFiL) on a master's degree level has been carried out by University of Klagenfurt since 1999. The individual courses are accessible only for a limited number of persons in order to ensure the quality of teaching (only up to 35 participants per programme). The courses are long-term in their duration (three one-week seminars and five regional group meetings at regional schools spread over two years). In the seminars, the participants design a development project for their own lessons and implement it in their own school between the seminars. They reflect on their practice through their own research diary, through student interviews, observations of invited colleagues, etc. and develop new ideas for cycles of action and reflection. Each participant writes smaller papers (reflective papers) and, finally, a thesis, which is published online. During the course of PFL, the participants experience a "professional community" which embeds their work in a seminar, based on the principles of mutual consultation and the external support of scientists from various universities.

The PFL courses provide in-service further education for teachers at colleges of education and teachers in the subject area of didactics and pedagogy, with particular emphasis on educational standards and competence-based education.

The graduates are qualified to accompany and support their colleagues in the further development of their teaching (school development projects). After successful completion of the compulsory courses and the positive assessment of the written examination, the participants receive a certificate of attendance from the University of Klagenfurt.

In UK, professional recognition awards

STEM learning actively encourage recognition among teachers, school and college leaders and policy makers of the crucial importance of career-long engagement with subject-specific professional learning. Significant developments in the last five years include the:

- establishment of the **Teacher and Support Staff Recognition Scheme** (recently rebranded the ***STEM Educators Award***), designed to recognise teachers, technicians and teaching assistants active in developing their confidence, knowledge and skills in STEM through professional learning and who can evidence positive impacts on themselves, colleagues and young people. The criteria for nomination include participation in in the equivalent of five days/year CPD, commitment to own subject-specific CPD, consistently good teaching and sharing good practice with colleagues, demonstrable impact on students. 101 teachers and technicians have received awards to date. The scheme is open to teachers and support staff working across the STEM subjects within any UK school or college on three levels:Effective STEM Teacher or Support Staff
- Leading STEM Teacher or Support Staff
- National Expert
  - introduction of the **ENTHUSE Celebration Awards**, presented annually to celebrate teachers, technicians, support staff and schools who, with the help of ENTHUSE and wider Network support, have made particularly noteworthy impacts on young people's outcomes in STEM. To be nominated teachers are asked to complete a self-evaluation form which states their professional learning and practice and impact achieved so far, attach evidence portfolio including references from their colleagues.
  - development of the **Science Mark** to recognise and celebrate inspiring practice in secondary science departments across the UK, which has been awarded to 29 schools since its launch in 2015. It works alongside and complements the Primary Science Quality Mark administered by the University of Hertfordshire. Similar to the awards described above, Science Mark is evidence based and has rigorous assessment criteria. Applying schools are expected to provide information about their teaching and learning practice in STEM subjects, including professional learning of their staff, evidence of improvement in the quality of subject teaching and of impact on outcomes for students.

"This [Science Mark] has had a knock-on effect with other teams, because they are seeing one department doing well, sharing, working well and they also want to have that same sense of accomplishment and pride."

By September 2018, our aim is for all Network CPD to be delivered by people holding the full CPD Quality Mark – around 350 individuals.

3.4.4 Finances of networks

Public funding is key to the sustainability of high quality networks of support for CPD.

In the five countries, public funding at a national and local level is used to fund different aspects of CPD mechanism: the Government may support the delivery of programmes (human resources), the bursary to pay for residential CPD, the budget to cover supply costs (where these are incurred) and also travel, etc. In some countries the government may also pay for replacement (supply) teachers for primary schools from a pool[4].

While core governmental funding is critical in most countries, CPD organisations have to find other partners, especially at local level, to supplement their budget and secure some resources that will contribute to specific local needs.

For some years, the support – both financially and in-kind, from industry and the private sector has been increasingly important as demands on government targets outstrip available capital. Engagement of the private sector can also be used to leverage additional funding not just from companies but often to draw on further central or local government finances (not directly linked to CPD/education).

Where the skills gap in STEM subjects is more acute, many employers are keen to ensure they are supporting schools to decrease the STEM skills gap – both in knowledge and employability skills. There is an increasing recognition that this support provides stronger links, contextual value and communication between industry and the education system and potentially enhances the progression of young people in STEM careers or further STEM study.

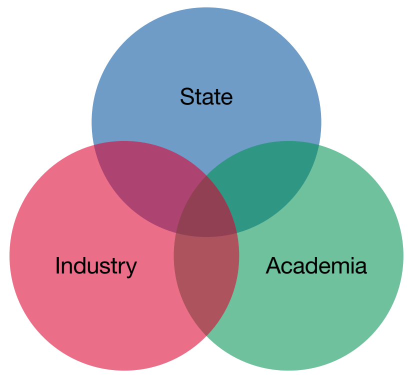
Still, lack of funding and prioritisation for subject specific CPD for teachers remains an issue. It is a high priority across all countries, leading to the support not being made available in those areas where there may be most in need i.e. areas of low social mobility, areas of deprivation and underachievement.

[4] For secondary teachers, as such replacement measures do not exist, local educational authorities should facilitate teachers' requests, for example by allowing them to move some of their lessons, or by setting up an organization within the school that allows teachers to go on training.

In some cases, industry and academic social responsibility has led to additional and targeted support.

However, for reasons of efficiency, but also for democratic considerations, we still consider it extremely important that CPD for teachers can be carried out independently and on a secure financial basis, which implies a strong commitment of public funding.

In short, the importance of subject specific CPD in fast moving, practical and skills based subjects requires financial security, prioritisation and investment from each stakeholder in the Triple Helix, where the State shall play a key role.



Source: Etzkowitz (2002, 2004), Etzkowitz and Leydesdorff (1998, 2000)

Fig. 9: Triple Helix Model

In Finland, a large support from the ministry complemented by private sector and local government

By far, the largest individual funding comes from Ministry of Education and Culture. For example, the ministry has given a six-year funding for LUMA Centre Finland with more than 30 STEM education related development projects that aim to support science teachers by offering them education and materials related to the new national core curriculum and related challenges. As LUMA Centre Finland network covers all Finnish universities, this funding can benefit to teachers all over Finland despite the geographical challenges of Finland.

Another essential funding comes from foundations and technology-related companies. For example, the novel nation-wide science fair model StarT coordinated by our national LUMA Centre Finland network that supports schools and encourages and educates teachers for implementing project-based learning is partially funded by the afore-mentioned companies.

Locally, universities and related quarters can provide CPD education for municipalities with various types of funding options. For example, the city of Joensuu and LUMA Centre of the University of Eastern Finland have made an agreement about offering CPD education for all local primary and secondary level science and mathematics teachers. One example of these is described in Example 1 - 1 about combining content knowledge and cutting-edge science.

In Austria, public engagement, mainly at central level, is the core of the funding

The IMST network activities are mainly financed by the Austrian Ministry of Education.

Every third year there is a possible prolongation through revision of IMST concept. The current IMST project runs through December 2018. Negotiations for its prolongation are under way.

- In the period 2016-2018 the IMST network runs on approximately: €1.5 million per year from the Austrian Ministry of Education and regional authorities (who finance its activities to a smaller share).
- Additional minor sponsoring is made sure through the co-operation with businesses like the Association of Austrian industrialist (Industriellenvereinigung) who e.g. sponsor the rooms for the yearly IMST day in their headquarters in Vienna.
- Adding to the above mentioned budget, the ministry of education adds 54 value units per year for federal teachers who work within the IMST structure (mostly one to two value unit(s) per person that get spend for IMST instead of the usual school work in their local schools).

In the UK, a large support from the Wellcome Trust and Government departments (The Department for Education and BEIS) are complemented by private sector funding from both National and local STEM Industries

Our ambition for a world-leading STEM education for all young people across the UK is shared by our ENTHUSE Partners and Supporters. ENTHUSE Partners provide financial as well as logistical assistance, collaboration and influence to help achieve this vision through STEM-specific CPD, while ENTHUSE Supporters provide influence and collaboration. In return, ENTHUSE Partners and Supporters are part of a UK-wide alliance supporting STEM education and skills – driving social mobility and improving young people's life chances, while addressing skills needs and preparing the UK for its future as a strong leader across STEM beyond the EU. The ENTHUSE Alliance has developed from its founding partners to a wider group of organisations committed to STEM education and young people. It now spans the engineering institutions and scientific societies as well as a wider representation of STEM employers, alongside Wellcome and the DfE. The number of partners providing financial support to ENTHUSE has increased, with the Institution of Mechanical Engineers, the Institution of Engineering & Technology, the Royal Society of Chemistry, the Biochemical Society, the Royal Commission for the Exhibition of 1851, IBM and the Institution of Structural Engineers joining the Alliance.

ENTHUSE remains fundamental to ensuring that all teachers of STEM across England and the rest of the UK have access to career-long, STEM-specific professional learning. Ongoing financial support from the Department for Education (DfE) and Wellcome is the cornerstone upon which this will be achieved. It provides a clear message that Government and Wellcome prioritise STEM teaching, so encouraging existing Partners to continue their support and attracting new funders to the Alliance.

A quinquennial review of ENTHUSE support and subsequent funding involves all stakeholders and is undertaken by an independent review panel. ENTHUSE funding allows the provision of bursaries to cover the cost of residential CPD, plus some supply cover and transport costs in some instances. It also supports STEM Insight placements and the CPD programmes delivered by our partners in Scotland, Wales and Northern Ireland. The Department for Education also funds the Science Learning Partnership Network which is reviewed every two years. The STEM Ambassador Programme is funded by the Department for Business, Energy and Industrial Strategy.

In France, a network which relies on public - private funding

The *Houses for science* network deploys its support in accordance with a strong principle which is the provision of free services for final beneficiaries i.e. teachers and pupils.

In order to allow access for all, the network relies on public - private funding.

An agreement over several years is signed with the Ministry of National Education and the Programme of the investments for the future. Locally, the regional education board is a primordial partner too, to co-organise and co-finance the training and travel of teachers and, as much as possible, their replacement.

Sponsorship, responses to specific calls for projects or calls for proposals coordinated by the national coordination provide complementary funding, subject to adequacy with the social mission. The network also seeks to involve active partners in each region in order to mobilise local resources that can have a leverage effect.

This combination of public and private funding reflects the network's strategy and positioning. The network is indeed at the same time an innovative player involved in educational research and in a development approach, and a player of the wider dissemination of innovations as well. While the first mission can highly benefit from flexible, well targeted funds, the second depends on a strong partnership with public actors for the deployment to greater scale.

4

The future of STEM CPD: the vision of LINKS partners

4.1 The proposed strategy

There are many possible models and strategies to enhance professional development, depending on the educational context of the country.

Nonetheless **some key elements can be identified as the core added-value of the members of the partnership in their national context.**

The capacity to provide consistent and comprehensive CPD programmes

Throughout their reflection, LINKS partners have identified their common capacity to respond to teachers' current needs in professional learning and resources, whilst opening up the development of knowledge, confidence and skills.

This requires different interventions, a few of them which have been identified are listed below:

- To provide multilevel courses tailored to the teachers' expertise and needs
- To promote common training initiatives in order to facilitate networking and learning in peer communities
- To provide the opportunity to become involved in the national/region STEM educators' network
- To design the long-term CPD courses in a hybrid way: from face-to-face sessions to distance learning with mixed synchronous meetings and asynchronous moments. A hybrid format allows attendees to take the time to test some pedagogical concepts in the classroom or during teacher training sessions, and to share their experience afterwards
- To encourage attendees to work in groups on projects (according to affinities, teaching level, etc.), even more at distance, is a key to success
- To provide teachers with time and support to reflect on and implement changes in their practice
- To enable access to a portfolio of online CPD supporting key aspects of STEM teaching, including subject knowledge, practical skills and assessment for learning
- To pursue lesson development side by side with school development
- To support partnerships - groups of schools working together and being supported to address issues of STEM achievement and participation
- To involve scientists and educators of different departments from the beginning to join forces in terms of content and finances, to opt for a long-term approach and to increase the impact (e.g. subject matter didactics, scientists, inclusive didactics, science innovators)
- To provide STEM insight placements enabling teachers to spend up to two weeks with STEM employers or university departments, with 'wrap-around' CPD to ensure embedding of STEM careers back into school or college curricula.

A proposed model of a comprehensive CPD programme, at any level

After the European projects Pollen and Fibonacci, partners developed a proposed model to frame a project, taking into account all the aspects that are necessary for its success at local level but also for its dissemination at larger scale.

The capacity to progress from pilot actions to larger-scale programmes: from innovation to dissemination

The pilot action can be a project on a local, national or international scale that represents a sort of "craftsman's workshop" where small prototypes are developed, but at the same time wider projects on a progressive scale are thought.

The size, the type and the number of the involved subjects may be different and it depends on multiple factors, but the pilot action duration must be at least two years, allowing the subjects to interact with each other for directing the plan to their needs and purposes, to improve the project and adapt it as well as possible to the field.

In parallel, a continuous reflection about what and how the available resources and relationships can be sustained over time and expanded in space is conducted. All partners in LINKS are aware of this double pillars dynamics: to proceed by small operational steps, but having really clear in mind the steps ahead.

In this process, the capitalisation of what already exist and what has been realized during an innovative project is paramount:

- the identification of existing resources avoids reinventing the wheel: in every educational reality there are many resources (also the professional ones) developed over time; the contexts and the educational policies evolution require adaptations and more or less profound revisits, but nowadays there is a large amount of resources that are freely available also through the web;
- the capitalisation of new resources or recommendations to implement a project facilitate the dissemination of good ideas and effective practices.

The capacity to remain close from local needs and dynamics and to enhance local results through networking

The scaling-up of programmes does not mean that a recipe shall be identified and applied to all teachers. When LINKS partners call for nation-wide mobilisation for CPD, this shall be considered in the sense of an attention to equal treatment for all teachers who all have professional development needs but not necessarily the same. That is why LINKS partners advocate for national strategies but quite flexible to allow for local adaptations, with a particular focus on the process of involving the whole school itself or small groups of schools in a given area.

CPD design and content should be driven by a relevant needs analysis. While local steering groups may be established to identify the needs of teachers, they are not always involved in further implementation. Where the strategy is locally defined (for instance school led) and based on confidence in the capacities of the teachers to build their own autonomy, teachers inevitably have a greater input into the design and content of resources and the impact of professional development is increased.

Of course, local dynamics need coordination and it is also important to connect them with others at regional and national levels in order to share experiences and highlight the global coherence of all initiatives. To address this purpose, partners have put a strong focus on the development of networks on the basis of a few principles:

- the agreement of all stakeholders on a shared vision and common goals;
- the provision of enough room for flexibility in relation with specific (local) needs and interest within the network structure, which means coordinators shall refrain from hierarchical interventions into CPD network activities;
- the existence of a framework structure that helps define and regulate network procedures and programme implementation;
- the allocation of financial means for the coordination of network activities including the time of all involved teachers;
- the assignment and support by educational policy makers of all network activities;
- the cooperation with research in order to enrich network activities, as its results feed back to the network structures and development.

The capacity to build a link between the scientific and educational communities and institutions

In the field of STEM, there is a profound tradition of school-supporting institutions and programs in all countries that are not embedded directly in formal educational structures but are closely linked to them. They were designed as programme tracks to cooperate with the public school system and other systems like research, regional development, or public institutions.

LINKS partners, even if diverse in status and organisation, are in this intermediary position in their respective school systems.

These intermediary institutions or programmes act as "missing link" providing a repository of scientific knowledge and specialist know-how in order to draw heterogeneous actors and institutions into new relations of co-operation (Meyer and Kearnes 2013: 424f). Meyer and Kearnes state that the rise of intermediary institutions and actors like LINKS partners has led to a reconceptualization of intermediary agency and practices of policy mediation and translation:

- not only do they act as connectors in aligning different worlds and translating between them
- they also collectively research new ways of co-operation
- and perform, constitute and define new scientific fields and fields of application
- they explore new logics (ibid.: 426)
- they see themselves as generators and supporters of innovation between top-down and bottom up interests for professional development
- Intermediaries also provide practical support (materials, workshops, workshop designs, off-campus learning centres, etc.)

LINKS partners are confident that these few trends can provide useful guidance for the implementation of effective and impactful CPD.

However, two main challenges remain at the core of the issue of systemic change.

4.2 The key challenges

The challenge of CPD for all teachers

The task of reaching teachers is not so easy for several reasons:

- Geographical reasons: Some teachers live in remote areas, too far from the cities, where the workshops are organised. So they cannot benefit from CPD face-to-face training sessions.
- Institutional reasons: Reaching teachers directly can also be challenging, in countries where it is necessary to go through principals, inspectors, municipalities… Teachers and unions may also want CPD only in working days.
- Organisational reasons: Teachers substitution during the CPD actions is a common issue and Head teachers may be reluctant to allow teachers to be released, especially at primary level. Secondary pupils are not covered when the teacher is absent so this is less of a barrier to attending CPD, but many teachers prefer not to miss lessons as pupils miss out.
- Financial reasons: Funding for substitution of teachers is insufficient. Teachers do not always receive money or reimbursement for their expenses during the CPD (travel, food). The cohort of substitute teachers available is usually insufficient.
- Individual reasons of teachers: A number of teachers also consider that being already at Masters level, they do not need further professional development. Sometimes training courses have to be organized in part out of service hours (i.e. afternoon, weekend or holiday) and are not economically incentivized.

Moreover, in-service training is only to some extent mandatory. It is rather attended by teachers on a voluntary basis.

As a consequence, teacher trainings in IBSE are repeatedly attended by the same group of teachers, so innovation is limited to a small group of teachers and the involvement of new groups and dissemination are an issue.

Besides, it is not easy to engage teachers in a long term perspective which is key for a systemic change.

To succeed in reaching all teachers and provide them with the diversity of CPD activities that we have developed to address their needs, a second challenge has to be taken up.

The challenge of sustainability

Sustainability is not only a necessity of financial resources, but above all it is also a matter of the professional development proposal quality, balanced by an adequate sustainability on the part of the teachers with the ability to welcome them in an evolving community where they can then be actors; in fact, the sustainability of the activities starts first from the people and from their shared vision, then from financial resources.

The sustainability of the activities is thus related to their planning, starting from the early design phases through short, medium and long-term actions, which derive from a shared vision of the objectives and methods of implementation. An accurate structural and functional architecture that contains key elements is needed and this planning has to be dynamic and able to respond to incoming context variations, in order to absorb and cope with them.

The sustainability of the activities is also directly related to the ability to respond to teachers' needs, which are set at the centre of the training process. When the proposed actions are able to deeply respond to teachers' needs (considering teachers as members of an evolving peer community), they are sustainable over time and have many different possible ways to continue.

In the preparation of this study it became also obvious that a central success factor lies in the presence of intermediary network structures that mediate between different disciplines and actors to coordinate and disseminate innovative developments. These intermediaries take into account the heterogeneous needs of the individual actors.

Since these intermediate networks often do not fall into any of the classic organisational categories in education (like schools or universities), it may be difficult to find recognition by the public hand and to maintain the resources required to carry out sustainable, continuous educational work.

Because of this peculiar situation, the networks very often conduct their activities through local, national and international projects; although these projects enrich and contribute considerably to the professional development of the involved participants, they are also strongly affected by being time and space limited. Therefore a very low percentage of available potential is really exploited in a large temporal and spatial dimension.

These challenges cannot be taken up only by CPD providers but require a larger mobilisation, especially from educational authorities, at all levels of decision.

4.3 Recommendations to decision-makers

Sustainability and scaling-up of quality STEM CPD are a major concern for LINKS partners, who need other stakeholders, and especially educational authorities, to join efforts for realising systemic change.

To this purpose, three main recommendations are proposed.

Educational authorities as well as the European Union should increase their recognition of the role and their support to the action of intermediary structures

Intermediary structures involved in STEM CPD have developed their capacities to both innovate and demonstrate the value of this innovation at a scale which is large enough to contribute to the prefiguration of public policies.

That is why LINKS partners recommend to educational authorities to increase or maintain their recognition which may take different forms:

- Enable the intermediary structures to work within the educational system to develop innovation with teachers, trainers, schools…
- Cooperate with intermediary structures to implement larger-scale projects that can prefigure tomorrow's public policies.
- Secure continuous financial support over the years, which is crucial for the sustainable development of the proposed CPD strategy.

Such recognition and sustained support have been possible to some extent in some countries (Finland, UK, Austria), and have constituted an important step forward.

In other countries, financing by the ministries often covers only part of the costs incurred or is limited to certain periods or specific topics.

That is why LINKS partners have increasingly invested in the continuous fund research for supporting existing activities and identifying long-term new projects with multiple sources, including private donors, foundations, employers, etc.

However, the management of multiple sources of financing remains a challenge for CPD providers and we do not see this as an ideal situation, rather as an emergency solution if the public sector does not assume its responsibility for education.

Therefore **LINKS partners strongly advocate the creation of sustainable financing structures at both national and international level to maintain interdisciplinary intermediary education networks and to promote innovation in STEM education**. Indeed, apart from national commitment, international projects, in particular those funded by the European Union, are an important source for the maintenance of the innovation capacity of intermediary structures and networks.

Educational authorities should lead the change towards a learning system

To be able to conduct a strategy of change, not only do students and teachers have to learn and change, so do educational research and policy. We see the whole system's need for learning. This makes it easier for teachers (and students) to regard themselves as learners.

If CPD programmes are to be impactful and based on cutting edge educational research, teacher educators need to be involved in the development and implementation of the programme. In developing such a programme, teacher educators need to integrate teachers' needs. Teachers need to experience that their engagement in CPD is relevant and worthwhile. In short, the whole system needs to be involved in the research, development, and implementation of national CPD programmes to positively impact teaching and learning in STEM.

That is why long-term CPD efforts should consider a systemic approach in educational research (providing a basis for teacher educators' work) as well as in educational policy and related administration (defining the context for teachers' work).

These assumptions point to a CPD framework that is general enough to be used in different contexts (students, teachers, and teacher educators), leading to the notion of the ''learning system'' (Krainer & Zehetmaier, 2013) in which four important poles shall be considered:

- Action
- Reflection
- Autonomy
- Networking

Though each of the pairs (''action and reflection'' and ''autonomy and networking'') are regarded as complementary dimensions that should be kept in a certain balance, traditional teaching and teacher education often underestimate reflection and networking;

That is why **LINKS partners recommend that CPD policies put the stress on the promotion of reflection and networking as key interventions.**

Indeed, once started, the possibilities within networks in education are manifold. They offer oriented exchange processes not only amongst teachers. Networks have the potential to create a culture of trust, with the effect of heightening the self-esteem, the autonomy and the risk taking of the teachers.

In the long run a balance of reflection and action (goal directed planning and evaluation) and autonomy and networking is paramount in order to set up a sustainable support system for schools.

Long-term ambitious policy for STEM CPD and STEM education should be adopted and maintained

National policies from the Ministries of Education –and European policies too- aim to get quick results, so sustaining in the long-term innovative processes that have proven to be effective and impactful is not always in the forefront.

However, change and innovation require long times and constant support; continuity appears to be the main characteristic of a successful policy: many different options can be chosen, there is no single model for STEM CPD and STEM education development, but maintaining a strategy over the years and guaranteeing stability in its implementation is essential.

That is why **LINKS partners recommend to educational authorities the adoption of long-term policy and planning, irrespective of political changes**. This policy shall be comprehensive and relate not only to in-service professional development, but to all aspects of the educational system: curricula, pre-service training, assessment of students' achievements, career management, etc.

Systemic change demands such comprehensive and stable policy. LINKS partners and certainly other CPD providers all across Europe, are keen on supporting this kind of policy in different ways, sharing their most successful innovation and prototypes for further ownership and supporting their scaling-up.

General coordination:
Laurence Constantini, Foundation *La main à la pâte*

Design:
Brice Goineau, Foundation *La main à la pâte*

Photographic credit:
LINKS

Published in June 2018 by the Foundation *La main à la pâte*, 43 rue de Rennes, 75 006 Paris, France

The LINKS project is coordinated by

Partners of the project

This publication is funded by the Erasmus + Programme of the European Union.