WP2 Synthesis: Summary Report, March 2015

Introduction: Synthesis of learning from STEM education projects in FP7/LLP

This summary report is based on a review of documents supplied by 20+ of the STEM (Science, Technology, Engineering & Mathematics) education projects funded in Framework Programme 7 and the Lifelong Learning Programme. This summary of the main report incorporates changes in European Commission thinking during the transition from Framework Programme 7 to Horizon 2020. These changes include broadening the potential range of methods, away from a focus on inquiry and towards a broader range of methods and players. The projects reviewed here are engaged in a pan-European movement towards innovative policies in STEM education.

The criteria for inclusion in the review were:

- EU funded, either by the Lifelong Learning or Framework 7 programmes
- Covering Inquiry-based science and/or mathematics (STEM) education, i.e. not education in general or Information Technology
- Taking place between 2007-2015

Key INSTEM Recommendations

A.1 Educational change in Europe should be implemented in line with a well-defined long-term vision, which incorporates the best features of national systems

A.2 There should be a wider interpretation of 'innovation' in relation to educational interventions, to allow for methods such as formative assessment and to avoid 'intervention fatigue' amongst teachers.

A.3 Greater coherence is needed between policies and actions in all education sectors, to avoid transitional problems caused by variations in methods and pedagogies, e.g. between primary and secondary.

A.4 There should be more interaction between science education, the world of work and research, in order to provide students with a sense of purpose and real engagement with science.

A.5 There should be more clarity about what constitutes impact for STEM projects and more systemic capacity to measure and monitor impact.

A.6 The duration of educational projects should reflect the long-term reality of school timeframes, in other words short-term interventions are not enough to ensure long-term change, even when 'multiplier' effects are taken into account.

B.1 There should be better alignment between pedagogy, curricula and assessment systems, ensuring that assessment reflects new teaching methods and that the curriculum facilitates inquiry rather than constraining it.

B.2 There should be better coordination between curricula, textbooks, online resources and teacher competence.

B.3 There is a need for more coherent and learning-oriented professional development programmes for teachers, in order to improve their confidence and repertoires of actions in relation to Inquiry-Based Learning.

B.4 More attention should be paid to student voice and rights in relation to STE(A)M subjects, in order to encourage students, as future citizens, to take responsibility for research and innovation.

C.1 The commitment of school heads and management teams is essential to implement new practices effectively. Inquiry-based learning has exciting implications for schools, teachers and learners, but schools are collective enterprises where teamwork, consistency of approach and fair sharing of resources are essential. Consequently, successful adoption of IBL requires commitment from school management, especially in supporting teachers to undertake the relevant TPD activities, including the provision of teaching cover where necessary.

C.2 Inter-disciplinary working and teacher collaboration are essential to maximise the potential of innovations in teaching and learning, hence the introduction of the 'A' (for All subjects) into STEM.

C.3 Teacher professional development requires time, space and coherent structures. One-off events are rarely successful in embedding new practices, which require time for reflection and ongoing peer-learning processes.

C.4: The informal sector has an increasing part to play in implementing innovative forms of science education. One of the major achievements of FP7 was that various national school-systems and teachers worked closely with SLIs in sharing knowledge, experience and resources for improving science education in Europe. Projects such as INQUIRE, Pathway or Fibonacci have focused on developing the role of SLIs in formal science education, to develop and publish teaching materials and to offer teacher professional development courses. SLIs are in the unique position of being able to provide resources as well as the up to date scientific content knowledge needed to support classroom practitioners when implementing IBL in their curriculum. Many FP7 projects therefore have implicitly or explicitly asked teachers to established communities of practice amongst SLI educators and teachers to help them develop a shared understanding of how inquiry based science learning can be supported in the best possible way at school and at the SLI (e.g. INQUIRE, PATHWAY etc.).

C.5: Classroom environment: The essential precondition for IBL to have any effect is an inquiry-friendly classroom environment, in which student questions are valued and curricula are sufficiently flexible to allow for deviations from planned lessons.

C.6 The role of prior knowledge, or 'enabling knowledge', has to be recognised, as there are many aspects of science or mathematics that do not lend themselves to discovery by students. Conversely, inquiry is not just 'hands-on learning' and the provision of resources or worksheets for activities with pre-determined outcomes is not inquiry in the true sense.

C.7: Professional networks: The demands of inquiry-based learning on teachers require a greater use of professional networks, including collaboration with other teachers, working with the informal sector and working with researchers on new methods, materials and topics.

Discussion

The evidence from projects is that effective TPD is the best and cheapest way of increasing the overall quality of teaching, itself recognised as the biggest single factor in improving student outcomes. On the other hand, projects also recognise, sometimes indirectly, that initial teacher education/training (ITE) needs to reflect the importance of IBL if it is to be internalised by teachers. ITE is a more difficult target area since it involves its own pedagogy, curricula, and assessment methods, and is often tightly controlled, as opposed to the rather laissez-faire attitude of educational autorities towards TPD. It is also a rather slow way of implementing change, since the number of teachers emerging from the ITE system each year is only a small proportion of the overall teaching population. Nevertheless, ITE needs to be targeted in any meaningful reform process, in order to promote the use of inquiry-based methods across the science education spectrum. Projects have been active in this area, e.g. the online web resources for initial teacher education provided by MASCIL.

The single most common theme from project documents and from the statements of teachers themselves is that professional development is necessary to enable teachers to implement IBL confidently and successfully. However, in recognising the qualities of IBL as a means of promoting better engagement and motivation in STEM subjects, we also need to recognise its effectiveness in teacher professional development. It is difficult to embed inquiry into teachers' practice through one-off presentations or one-day workshops

Firstly, setting out principles for inquiry-based activity does not mean that the application of those principles is unproblematic. The best way of dealing with these problems is to give teachers the opportunity to get together with their colleagues and with external researchers, before, during and after the introduction of IBL activities or methods into the classroom. This requires regular time and space to be provided, either in schools or in other local facilities, for teachers to meet on a regular basis. Furthermore, there needs to be a clear purpose for such meetings, ideally located within a long-term structure for teacher professional development. This requires the involvement of educational governance in setting goals for TPD.

The recommendation that teacher professional development should be conducted in communities of inquiry builds on a wide range of recommendations for teacher professional development and is connected to requirements in Calls for Proposals regarding the involvement of teacher networks.

The key element in a Community of Inquiry is that an educational experience should be at the heart of the inquiry, and this should be approached through a process in which all voices in the community have equal value. These communities, however, do not often emerge spontaneously, and input from researchers or teacher leaders is important in the initial stages.

Inquiry-based learning exists only when the broad principles of inquiry come into contact with the complex details of curriculum, classroom environment, individual learners, teacher knowledge, assessment systems, physical resources and so on. It is difficult to specify exactly what the right actions might be for a given situation, without being in the position of the teacher (or students) concerned. This is primarily the role of those working at the local or national level.

At the time of writing, there are three major FP7 projects specifically addressing assessment, and this will undoubtedly produce a much better foundation for future applications of inquiry. In terms of the curriculum, we are seeing some indications of change towards curricula based on what the National Science Association in the US calls 'cross-cutting concepts' and 'disciplinary core ideas'.

Teachers and students work within a 'pedagogical field' (Gray, 2009), which determines the parameters for action within any given education system. This field has trans-national, national, regional, local and micro-scale components, including relevant policies and legislation, traditions, teacher education frameworks, curricula, assessment systems and emerging trends. The right of students to ask questions, meanwhile, is increasingly regarded as a necessary part of a creative and curiosity driven educational environment, although in certain national contexts it is still not universally accepted.

Although this point has been mentioned before in this report, it is fundamentally important, since the overall aim of improving student engagement requires projects to at least acknowledge the importance of student perceptions of inquiry. This is one of the most notable absences from project documents, but there are a number of reasons why the student voice is not there, at least in adequate strength. Those projects that have done work on student opinion, such as SECURE, have not investigated inquiry directly, either because it is absent from school 'language', or because it is not being used at all. It is therefore difficult to get a clear picture of whether, and how much, students value inquiry and whether it might affect their long-term intentions. Other projects, such as SiS-Catalyst, have addressed student opinion in a more direct way but are not primarily concerned with IBL.

We strongly support an overall vision of implementing IBL on a wide scale across Europe. However, as was noted in the previous section, the principles of inquiry should apply to change processes as well as to teaching methods. Thus, it is necessary to inquire into how the vision looks now and what the next stage of the vision should look like.

Overall, projects have initiated extensive European collaboration, have inspired thousands of teachers and have undoubtedly enabled many more thousands of pupils to enjoy science more, to engage with it more, and, for some, to take it up as a career. However, we need to construct a more robust vision of educational progress, one to which students and teachers can subscribe without the initiative fatigue mentioned in the previous section. Linking this vision to societal challenges might open up the possibilities of involving a wider range of stakeholders and a wider range

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of methods. As the above recommendation suggests, imaginative local actions, perhaps unforeseen in the development of large projects, should be nurtured. This is in line with the EU's own espousal of social innovation, and also with the conclusions of the recently-completed Xploit project, which looked at learning communities[1] and how they could be sustained.

The most important factor in presenting such a vision is that it should be the co-creation of those involved, including students and teachers. This is not to exclude scientists themselves, although the real need is not for one off visits but continued engagement, something more possible for science students and early-career researchers than for Nobel prizewinners, often cited as possible role models. Sustained engagement with scientific activity over long periods can help to provide the necessary insight and inspiration for young people to choose science-based careers or to use scientific tools in their daily lives.

It is also important to see science education in the context of the Responsible Research and Innovation (RRI) agenda. Science education has traditionally been seen as value free, but in RRI, we are seeing a return of values, ethics and critically, public engagement with science. Inquiry-based learning is vital in enabling students to engage with science and scientific processes through observation, data collection, analysis and argumentation based on evidence. Many STEM projects have taken the bold step of connecting school science to science in action, by linking researchers and students. The resulting dialogue is at the core of science education within RRI.

Our vision for science education is one of openness, where there are no boundaries between science and education, or between research and learning. This means that inquiry, in a wide sense, should be at the centre, as the connecting theme between all relevant activities, as in the diagram overleaf:

School management, and the local education authorities or other regional bodies, also have a role in providing the necessary physical resources for inquiry. In some countries, the outreach role of universities is pivotal in providing access to advanced laboratories and other facilties beyond the financial reach of individual schools.

Research has shown that school visit to science learning institutions (SLI), such as science museums and centres, become more effective when these visits change from being "add-ons" to "add-ins" to the formal science curriculum. Teachers who offer pre- and post processing activities in class support their students most efficiently in achieving higher learning outcomes (Cox-Petersen et al, 2003). In addition, it is most helpful if SLI educators are informed about students' prior ideas, knowledge and understanding of particular scientific concepts addressed during the field trip. This is a great step forward in joining forces for future work on improving science education in Europe. However, a culture of reflective practice as well as knowledge sharing and experience was also established amongst SLIs themselves (e.g. in INQUIRE), which will improve their proficiency in creating science learning environments. FP7 projects all over Europe helped to raise awareness of the important role of SLIs in supporting national formal education systems and meeting 21st century science education goals.

The most relevant aim of using inquiry is, by general agreement of all projects, to increase student engagement with science topics. Providing a classroom

[1] *http://xploit-eu.com/thexploitproject/*

environment supportive of this aim would seem to be simple, but in fact it is not obvious, and is a skill, which good teachers are able to deploy once learned, whether in initial teacher education or in professional development courses. Many of the projects, including Fibonacci, Pathway, PRIMAS, PROFILES, S-TEAM and SAILS provided such professional development courses aimed at creating classroom environments supportive of inquiry.

Conclusions

The process of synthesising the project knowledge and learning from more than six years of intensive activity has provided many insights into the patterns of activity emerging from a particular kind of situation. We have seen that projects in this field have many commonalities of approach and have worked hard to succeed.

We therefore need permanent structures and channels through which to promote IBL, to train teachers in its use, to empower teachers to develop their own ways of doing inquiry and most importantly, we need to involve students in design and implementation. We also need to set out a sustainable plan for changing educational culture in order that student voices can be heard and that teachers can adopt the most effective methods regardless of their origin. We are sure that the support of the science and mathematics education community will be forthcoming in achieving this.

Projects analysed in producing this report

Name	Website	Dates	Fund
ASSIST-ME: Assess Inquiry in Science, Technology and Mathematics Education.	http://assistme.ku.dk/		FP7
CARIPSIE: Children as Researchers in Primary Schools in Europe		2007-2009	LLP
COMPASS	http://www.compass-project.eu/	2009-2011	LLP
Creative Little Scientists: Enabling Creativity through Science and Mathematics in Preschool and First Years of Primary Education	http://www.creative-little-scientists.eu/	2011-2013	FP7
ESTABLISH - European Science and Technology in Action: Building Links with Industry, Schools and Home	http://www.establish-fp7.eu/	2010-2013	FP7
FaSMEd: Raising Achievement through Formative Assessment in Science and Mathematics Education	http://research.ncl.ac.uk/fasmed/aboutourproject/	2014-2017	FP7
FIBONACCI	http://fibonacci-project.eu/	2010-2013	FP7
G@me: Gender Awareness in Media Education		2006-2009	LLP
Hands-on Science		2003-	LLP
HEGESCO – Higher Education as a Generator of Strategic Competences		2007-2009	LLP
INQUIRE - Inquiry based teacher training for a sustainable future	http://www.inquirebotany.org/en/	2012-2013	FP7
Irresistible – Engaging The Young With Responsible Research And Innovation	http://www.irresistible-project.eu/index.php/en/	2014-2017	FP7
LEMA		2006-2009	LLP
MaScil	http://www.mascil-project.eu/	2013-2016	FP7
NTSE - Nano Technology for			

Science Education			
Open Science Resources (E-ContentPlus; Ecsite)			
PATHWAY	http://www.pathway-project.eu/	2011-2014	FP7
PENCIL (Permanent EuropeaN resource Centre for Informal Learning	http://www.xplora.org/ww/en/pub/xplora/nucleus_home/pencil.htm	2004-2007	
PREDIL - Promoting Equality in Digital Literacy			LLP
PREMA 2: Promoting Equality in Maths Achievement 2			LLP
PRIMAS - Promoting inquiry in Mathematics and science education across Europe	http://www.primas-project.eu/en/index.do	2010-2013	FP7
PROFILES - Professional Reflection-Oriented Focus on Inquiry-based Learning and Education through Science	http://www.profiles-project.eu/	2010-2014	FP7
SAILS - Strategies for Assessment of Inquiry Learning in Science	http://www.sails-project.eu/portal	2012-2015	
SECURE	http://www.secure-project.eu/	2010-2013	
SIS CATALYST	http://www.siscatalyst.eu/	2011-2014	FP7
S-TEAM - Science-Teacher Education Advanced Methods	http://www.s-teamproject.eu/	2009-2012	FP7
STENCIL		2011-2014	LLP
TEMI – Teaching Enquiry with Mysteries Incorporated	teachingmysteries.eu	2013-2016	
TRACES	http://www.traces-project.eu/	2010-2012	