INSTEM

Shaping the future of STEM education

CASE STUDY:
THE TRACES PROJECT

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1. WHAT IS TRACES

The main idea behind TRACES (Transformative Research Actions – Culture and Education in Science)[1] was to look radically at the factors that are holding back formal education systems from moving into more effective science education. A radical approach implies an holistic view that takes all aspects emerging as relevant into account (e.g., not just sheer pedagogy) and drawing the necessary implications. The assumption was that only then can actions actually be transformative. We will go back on this later in the report.

At the time when the proposal was presented (2009) a number of calls in the *Science and Society* area of the 7th Framework Programme were looking at ways for improving science education in the direction of a more learner-centred, inquiry-based approach.

The introduction of Inquiry-Based Science Education (IBSE) into school pedagogy was assumed – in particular after the publication of the so-called Rocard report to the Directorate-General for Research on good practice in science education (European Commission, 2007) – as a key factor for improving the learning of science and raising young people's interest in science studies. This also reflected a broad consensus in the research literature, despite some controversy about the evidence base in which the consensus was grounded (see, e.g., Cobern et al., 2009).

Numerous EC funded projects engaged in actions aiming at spreading IBSE, both further researching into the implications of IBSE, its definition and implementation in the classroom (e.g., PATHWAY) and developing and implementing of dissemination models (e.g., FIBONACCI).

The Rocard report's starting point was that "despite the numerous projects and actions that are being implemented to revise this trend [of decline in young people's interest for key science studies and mathematics], the signs of improvement are still modest." From the point of view of research, this for us was a known issue. Research literature had been promoting a more learner-centred, problem-oriented, constructivist approach to (science) education for decades. Implementation methodologies to different degrees of specificity as well as a plethora of exemplary resources and materials for students and teacher had been developed and made available to support change in the classroom. However, research literature as well as international studies like PISA and TIMMS clearly indicated that the impact on classroom pedagogy and students' learning was very limited and mostly episodic in character.

In designing TRACES, our goal was to investigate into factors involved in this research-practice gap by working together with school teachers in a holistic approach that should not neglect factors that might be considered secondary either by themselves or in terms of their interactions with one another.

This implied an action-research approach in which research should take place in an authentic situation in which the complexity of involved factors would emerge naturally from the joint researcher-teacher work. In carrying out the work, we applied a collaboration model aimed at addressing some of the known issues related to similar actions and to teacher professional development in general.

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In particular, the model implied:

- participatory approach: (negotiated contents and structure, common decision making processes)
- peer-to-peer interaction: each actor is considered an expert in their own field even if roles are different; actors validate one another; talk about roles (researchers bringing research indications, coaching, introducing laboratorial equipment etc., moderating forums)
- research is seen as an integral component of the teaching practice
- situated intervention: work is based on materials produced by the workgroup
- classroom activities are a crucial component (validation, demonstration of relevance of the proposed pedagogy etc.)

To insure some degree of generality, actions were carried out in schools of different geographical (cultural), socio-economic and grade-level schools. And, of course, in each of the six participating countries.

It is important to notice here this kind of intervention would not have been sustainable in the context of the normal activities of both the researchers and the teachers. That is, that the educational systems in each country do not provide the necessary resources and structures for such actions to be implemented.

2. TRACES FINDINGS

Research carried out in the framework of the TRACES activities over a period of almost two years in six countries provides a vast richness of insights that often go well beyond the research focus of the project, i. e. the relationship between research and practice in science education.

This is consistent with the project's research approach, aimed at identifying the actual constraints that influence research-based practice in science education and the actions developed in order to promote it and to address the project's research questions in terms of the complex system of factors involved. This applies in particular to the case studies, which constitute the core of the TRACES research programme.

Working with teachers in the framework of actions aimed at promoting research-based science teaching implied addressing, along with the more strictly disciplinary and pedagogical issues, equally fundamental questions such as those related to teacher pre- and in-service training, those related to the relationships among teachers and with the principal in the school, those related to the local context in which the school operates, such as the relationship with the territory and the local community, those related to the broader (national or regional) context such as the relationship with administrative and supervising institutions, the education policies, the official curriculum and summative assessment procedures.

These elements play an important role in teachers' work and have to be taken into account when designing transformative actions, that is, actions aimed at changing practice.

Change implies questioning consolidated practice and involvement in the broader debate on science education in a process of continuous reflection and professional development.

This process is promoted by interaction with colleagues in the same school and with external actors such as researchers in science education or teachers from other schools or educators from the informal sector.

TRACES research shows that teachers can largely benefit from increased opportunities of sharing their experiences and reflections in a group that works together identifying common issues and strategies.

Such groups include discipline related groups such as science departments of different kinds according to the school cycle, cross-disciplinary groups, cross-grade groups in the same cycle, crosscycle groups in comprehensive institute etc.

Our findings support the growing consensus (see Stoll et al., 2006 for a recent review) that developing professional learning communities promotes change in teaching by supporting reflective practice and professional development.

In the schools where teachers are used to work in groups with colleagues from the same school or in networks with nearby schools, TRACES field actions found a richer soil for common growth and effective exchange among teachers and with the researchers involved.

Issues which are recognized as shared by the group are more effectively addressed because selfconfidence and motivation are strengthened. This also enhances teachers' attitude towards a perturbation to the ordinary work such as the one related to the interaction with the researcher. Moreover, a group of teachers who are able to establish common interests, needs, objectives are more likely to play an active role in creating or selecting targeted opportunities of professional development both in terms of structure and content. Such a bottom-up approach to the definition of specific professional development paths for different groups of teachers seems indeed promising in addressing the lack of coherence and systematicity which research identifies as one of the main issues in traditional professional development programmes (see e.g. Villegas-Reimers, 2003; Guskey, 2002).

Another element emerging as crucial to the impact of research on practice is teachers' perceived relevance of research results to their everyday practice. Relevance emerges as a key factor in teachers' relationship to research-based stimuli aimed at promoting change as they may receive through official indications and curricula, research literature, training or other professional development programmes.

As any other research sector, research in science education is specialized in its language and norms, which are established and recognized by its reference community. In order to set up an effective dialogue with the different communities of practitioners, mediation is needed in terms of what content is identified as most relevant and what language is appropriate.

Past and ongoing European projects have addressed the research-practice gap by selecting research literature and presenting it in a more accessible language (as e.g. the resarch2practice project, aimed at practitioners from the informal sector) or by disseminating well established research results through training (e.g. Pollen, Fibonacci, Inquire).

In most of TRACES field actions, researchers worked in schools with small groups of teachers trying to establish a participatory approach to the common work, in which researchers and teachers, notwithstanding the specificity of their competencies and roles, would cooperate as peers. This

implied involvement in the decision making process regarding both structure and content of the action and co-responsibility in the implementation and evaluation of the programme.

In agreement with earlier studies (see e.g. Day, 1997) our findings suggest that if participants develop a sense of ownership of the programme, the programme is better received and more likely to have an impact on practice.

Analysis of TRACES field actions suggests that teachers' sense of relevance of the actions' content is strongly corroborated if researchers and teachers interact in concrete settings such as classroom activities with students. Shared classroom work strengthens teachers' trust in the researcher and the educational approaches the actions aim at promoting and demonstrates their relevance to everyday practice in that they are confronted with real-world constraints. The classroom is perceived as the most reliable testing ground where the reflections developed at the researcher (or trainer)-teacher level can be evaluated in terms of soundness and applicability. By conducting activities side by side with the researchers, teachers are also more likely to develop a sense of confidence with regards to the promoted pedagogy and the necessary autonomy for incorporating related stimuli in their practice in the long term. Our findings suggest that this applies to both training programmes and to more general professional development programmes such as teaching experimentations or actionresearch programmes. As a broad corpus of research suggests (see e.g. Donovan et al., 1999; Newman et al., 1995), 'authenticity' promotes long-term learning and teacher learning should indeed make no exception.

The ideas of co-responsibility, ownership and relevance also emerged as key features in another structural element in a systemic view of school and teaching.

While some of TRACES case studies were specifically focussed on issues related to the interaction between the school, the community and the local socioeconomic and cultural specificities, also in other case studies and the workshops conducted during the final conference these proved to play an important role in the way science is taught at school.

Teachers involved in our research programme seemed to support the idea that the school should be seen as a collective construction in which teachers, pupils' families and other members of the community should be involved.

The idea of ownership and co-responsibility correspond on one side to seeing the school as an integral part of the community. An effective school is flexible to the needs and culture of the community in which it operates and with which a mutual recognition of norms, values, visions is needed. On the other side, the community should be seen as an integral part of the learning process of the pupils and it should take responsibility in what happens at school.

Teachers' work is most likely to have an impact on the students if the learning process is supported by the families and more in general by the local community and if the role of the school in the community is recognized and valued.

The support of the community appears even more decisive when the school is committed to experimenting innovative pedagogical approaches. In the framework of the TRACES field actions, teachers explored a number of different strategies aimed at involving the community while implementing research-based approaches to science education. Teachers' choices in terms of content also proved to be most effective when the content was recognized as relevant by the families and the local communities. For example, in rural communities in Argentina and Colombia,

teachers involved in the TRACES field actions focused their work on content related to local needs such as running water or devices powered through solar energy.

Taking the local needs and interests and the cultural specificities of the community in which the school operates into account requires that the school's choices in terms of content and pedagogy enjoy a certain degree of freedom. In other words, that external constraints such as the national (or regional, according to the country's educational system) curriculum and assessment prescriptions are flexible to a certain degree.

A flexible national science curriculum requires that fundamental learning goals are identified, around which a more specific content can be selected at the school or class level according to emerging needs. Although there is growing research commitment aimed at identifying scientific core ideas and related learning progressions through the grades (see e.g. NRC, 2012) further effort seems to be needed in this direction. Impact on the educational policies, science curricula and teacher training appears very limited.

For a more complete exposition on TRACES' findings please see Balzano et. al. (2012) and Balzano et. al. (2014). A section of the first document is annexed to this report in Appendix A.

3. IMPLICATIONS OF TRACES

TRACES involved European and South American countries and very diverse cultural and social settings. It is important to highlight that the considerations that follow are based on analyses produced and shared by the whole project consortium and represent issues, indications and crosscutting themes in science education.

While many implications of TRACES are already evident in the findings themselves (and more so in the recommendations in Appendix A), we would like in this section to focus in particularly on some that we consider most relevant for the aims of INSTEM and because of the extent to which they might informe future projects.

For many of the researchers and teachers involved in TRACES the project was an experience of deep and long lasting impact.

In particular, the open-ended approach of the actions and the commitment to genuinely listen to teachers needs, values and perspectives on the issues addressed and let relevant factors emerge from authentic contexts provided a powerful insight into the complexity of the subject.

It indicated that attempts aimed at changing school pedagogy without taking this complexity into account and in a top-down approach may be simplistic and likely to fail when seen at the large scale and on the long term.

This reflects the character of radicality of the project and its findings which we anticipated above and can now be further explained.

As also confirmed by perspectives emerging from a discussion group we held with school teachers and principals in the framework of the INSTEM national workshops (see Appendix B for a full report) and from our daily interaction with teachers of all grades, the issue of improving science education requires a systemic approach. A concerted interaction of actors such as researchers (universities),

teachers, providers from the informal sector, local administrators, students' families and the local community in general is necessary.

An effective interaction requires structures explicitly devoted to it and these cannot but have a local distribution. In Italy, there existed interesting examples of such structures embodied in the so-called Regional School Offices. The trend in policy in the last decades has been however rather in the direction of slowly dismantle these centres than strengthen them.

Many of the teachers we have worked with in the framework of TRACES and other programmes referred to the role played by the Regional School Offices in the past as examples of good practice. For example, these institutions played an important role in coordinating the interaction between (science) education scholars and teachers and provided targeted opportunities of professional development based on the needs of the teachers in the local school. This in turn enabled teachers to determine their own in-service training path in a coherent fashion, thus addressing one of the known issues of teachers' professional development.

TRACES also suggests that many resources are readily available if there is the will and the capacities to acknowledge and make the best of them. For example, a reorganization of teachers' nonclassroom activity in the direction of a structured and reflective cooperation with colleagues in communities of practice and learning and a more diversified offer of professional development opportunities for teachers to choose themselves from would not imply great investments. Initial teacher should correspondently also designed in order to foster a culture of cooperation and of teaching as a reflective practice.

It is evident from these considerations that the implications for EU funded projects aimed at improving science education are also radical.

It is a long debated theme if the European Commission, or the Directorate General for Research and Innovation in particular should directly address national institutions such as the ministries of education or similar bodies responsible for education policies on the national or more regional level.

It is our experience in TRACES and numerous other small and large scale projects that expectations of significant impact on science education in the absence of such commitment are destined to be episodic and limited.

In particular, our findings in TRACES – but there exists also extensive research literature on the subject – indicate that as soon as one engages in a programme aimed at addressing school pedagogy in an authentic context, it becomes immediately evident that a number of other factors that cannot be addressed by the single programme of, say, teacher professional development, condition and constraint the process in a decisive measure.

Another point that diserves attention regards more specifically pedagogy. Although our actions in the framework of TRACES did not include assessment of students' learning, the fact that our intervention model involved both work with the teachers alone and with students in the classroom provided an opportunity to observe inquiry-based teaching in an authentic context and record teachers' perspectives on the subject.

This experience supports our assumption (based on existing research) that training teachers on the sheer application of an inqury-based pedagogy with its componets of asking questions, making observations, formulating hypotheses, planning and executing investigations, interpreting data, reporting findigs etc. is a naive approach to the problem of improving science education and that

many other factors should be taken into account that might well prove decisive in the actual effectiveness of classroom teaching. These involve, for example, classroom norms and climate, from the management of difference, portrayed (explicitely or implicitely) images of knowledge and (epistemology) to details as specific as the way teachers ask questions and so-called 'wait time' (the time they wait for students to answer them) (see, e.g., Black et al., 2003).

The relevance to pedagogy of such aspects emerge immediately when work with teachers is conducted in parallel at the researcher-teacher level and the classroom practice level. Moreover, this kind of work showes that the impact of a teacher professional development programme (in terms of long-term change in practice) is crucially dependent on the programme being specifically tailored on the participants. Addressing issues emerging from real-world and personal teachers' experience in the classroom demonstrate the relevance of the proposed solution with regards to teachers' practice and therefore supports change.

This speaks against professional development programmes based on ready-made recipes for inquirybased teaching and materials developed indipendently of the participants in the programme or even at international level and then implemented top-down on teachers in the very different cultural and socio-economic, if not personal, contexts in different European countries. Approaches of this kind seem also intrinsically problematic, in that they aim at promoting a learner-centered, participatory pedagogy while enacting a teacher-centered, top-down pedagogy (where in this case the teacher is the trainer).

Looking at the smaller scale of the impact on our institution (or better to say our Science Education research group), while it seems natural for a research project to mainly impact on participants' awareness and beliefs, it is not difficult to see which implications the project implies for our future activities.

In particular, confirmations of the effectiveness of a participatory approach to teacher in-service training coming from the experience in TRACES will (and has been already) more definitely shape the character of our interventions of this kind.

In the part of our activities involving pre-service teacher training we are also more keen on focusing on those aspects that foster a culture of cooperation and portray the school as a possible node in a broader landscape of bodies, groups, associations and individuals that may contribute to its goals.

This message we are also spreading to our colleagues on the national and the international level and many of the findings from TRACES are at the core of our last publications.

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APPENDIX A – COMPLETE FINDINGS AND RECOMMENDATIONS

THEME 1: Cooperation among teachers

Even if teachers spend most of their working time alone with their students, the relationship with colleagues plays an important role in their everyday practice. Along with the tasks institutionally appointed to collegial organs such as the school or class council, the science department etc., teachers share their experience, beliefs, perceptions in many formal and informal situations. In smaller or larger groups, teachers take decisions about curriculum, pedagogy, assessment, in-service training and work organization that are then reflected in their classroom practice.

A large majority of the teachers involved in the TRACES large-scale national surveys referred to better opportunities of cooperation and exchange with colleagues as one of the most relevant factors for improving science teaching in their schools. When asked about sources of conceptual stimuli about teaching and factors that influence their practice, teachers in our sample mentioned interaction with their colleagues among the most important elements.

In TRACES field actions, researchers from each partner team involved groups of teachers from schools of all grades in activities focusing on research-based approaches to science teaching. In some cases the groups shared a history of cooperation and professional development, in other cases, the group involved teachers who were not used to work together on a deep level of reflection.

Analysis of our case studies suggests that the impact of the activities was influenced by the extent to which participants were able to share needs and visions and work together as a group.

In Italy's CS1 and CS2, two groups of teachers with comparable levels of experience in both practice and professional development were involved in similarly designed programmes. In both cases, decisions about both content and structure of the programme were taken collegially. While teachers in CS2, who were able to identify common interests and objectives and take decisions accordingly, expressed general satisfaction for the programme, those in CS1, who clearly were less used to shared reflection, found it hard to agree on suitable programme content and finally lamented the scarce relevance and limited effectiveness of the programme. Notably, the second group included teachers from two formerly distinct schools just recently united in a comprehensive institute.

Involvement in a professional development programme in interaction with external actors such as researchers or teacher educators or expert colleagues is – together with specific pre-service training – the most relevant opportunity for teachers to be exposed to educational research.

Teachers who are used to cooperate with colleagues and able to establish common interests, needs, objectives are more likely to play an active role in creating or selecting targeted opportunities of professional development both in terms of structure and content. Such a bottom-up approach to the definition of specific professional development paths for different groups of teachers seems indeed promising in addressing the lack of coherence and systematicity which research identifies as one of the main issues in traditional professional development programmes.

As some teachers also highlighted, however, given the limited opportunities for professional development and more specifically in-service training activities, sometimes very few or even a single teacher in an entire school will be able to take part in such activities. This also partly depends on teachers' willingness to travel to another city or to invest part of their free time.

Also in this case, a group of teachers that make reflection and discussion an ordinary part of their work will be more likely to be able to take advantage of professional development experiences of single colleagues when they are shared within the group.

In any case, a practice of science teaching which is open to reflection and innovation based on stimuli coming, *inter alia,* from research results implies questioning ordinary work in light of an external stimulus that may – or

may not – provide more effective approaches to teaching. In this regard, teachers in one of the final TRACES workshops interestingly referred to a 'perturbation' of an existing equilibrium.
TRACES research suggests that accepting such a perturbation requires strong motivation and confidence and that being part of a consolidated group of colleagues promotes both motivation and confidence. Sharing issues within the group implies opportunities for mutual support and for the exchange of competencies and experiences that may enrich and ease the work of all colleagues.

In many of the TRACES case studies, the presence of an external actor represented a catalyst in teachers' group dynamics, facilitating processes, promoting commitment, creating a virtual space for interaction to take place in situations in which even existing structures (for example the science department in the school involved in Italy's CS7) were not effectively exploited.

Teachers identified lack of time and appropriate organizational structures as the main barrier to cooperation with their colleagues. The opportunities for working together, for example conducting activities in the classroom or exchanging roles of conductor and observer, and for meetings in the broader group are limited and scarcely acknowledged. Notably, institutional pre- and in-service training programmes usually do not include cooperative work activities.

Teachers in Spain's CS1 (see e.g. p. 65) referred to ordinary work organization as a 'trap' that forces committed teachers to make up time to devote to shared reflection by renouncing to personal needs.

In Italy's eight case studies, researchers provided involved teacher with online community tools through the TRACES website with the aim of promoting exchange of insights and materials. The tools included discussion groups, a repository of files aimed at the exchange of materials, and a blog tool to post comments about the development of the work, activities in the classroom, emerging issues etc. Although there was in fact very limited use of the tools, many teachers remarked their usefulness and suggested that resistance may be ascribed to the novelty of the medium and be easily overcome if the tools become integral part of the ordinary work.

Some teachers highlighted that the kind of work we were carrying out in the framework of the TRACES activities (see e.g. CS2) was indeed demonstrating the relevance of online tools such as repositories of materials and discussion forums to their teaching practice. It was also evident, though, that a key success factor was the fact that the materials collected and the discussions were strongly contextualized in that they were part of a wider programme including meetings in person, activities in the classes etc.

In the absence of preparation and awareness, even existing opportunities for teachers to meet and share reflection, such as the science department or the inter-class meetings often turn into service duties devoted to the accomplishment of bureaucratic tasks. Teachers in Italy's CS2 described a situation in which interaction tends to crystallize around tasks perceived as bureaucratic requirements such as the yearly programme[2] development and there is indeed no real dialogue on deeper elements relevant to the teaching practice.

Prospective science teachers involved in pre-service training in Brazil's CS3 emphasized the relevance of cooperating in communities of practice and reflection groups and suggested that students accessing the courses should be selected according to their interest and availability to share experiences and reflection with colleagues.

Many teachers pointed out that, for the interaction to be effective, the level of the discussion should address fundamental questions such as visions of education and of science education in particular. Teachers in Spain's CS1 considered the opportunity to share reflections on science teaching in a research approach that involves deep analysis and evaluation of classroom activities with the aim of informing practice. The process seemed to

[2] As opposed to *curriculum,* the term *programme* refers to a mere list of subjects to be covered. Every year, teachers are required to devise a programming for the next school year.

be promoted by collaborative design of classroom activities, which provides a concrete common ground on which to share reflection on both disciplinary and pedagogical aspects.

The possibility of structuring the curriculum according to specific school or classroom needs was particularly valued by teachers involved in the TRACES research. This was for example the case in Brazil's CS2 (see e.g. p. 89), in which official indications granted sufficient flexibility for mixing classes into larger groups of students for teachers to carry out classroom activities in teams. Colombian (see e.g. CS2, p. 111) and Argentine teachers emphasized the need for national curricula to be general and flexible enough to adapt to local cultural and socioeconomic specificities with regards to the local community or the single class (see also THEMES 5 and 7).

Discussion on fundamental aspects such as the vision of teaching, the structure of the planned and implemented curriculum and students' assessment emerge as particularly relevant when teachers from different cycles interact. While official indications often emphasize the importance of continuity along cycles (verticality), school systems often display fractures in approaches related to different teacher preparation and selection, curricular structure, assessment procedures etc. Opportunities for teachers from different cycles to meet are also very limited. In Italy, recent reform is promoting the formation of comprehensive institutes including kindergarten, primary and lower secondary cycles.

For teachers in newly formed comprehensive institutes (see e.g. Italy's CS1), involvement in cross-cycle boards such as the science department represent both a challenge and an opportunity for sharing reflection about verticality issues and exploiting one another's specific competencies. In Italy's CS8, differences related to the vision of the role of the teacher and his/her responsibility with regards to students' learning seemed to represent a serious barrier in understanding how work in a higher cycle may build upon development in the lower cycle.

Sharing reflection and discussing within a group implies sharing doubts, difficulties, limits, and exposing one's own practice to public criticism. This is a demanding process and requires favourable conditions to be promoted. In particular, mutual observation of classroom practice, which many teachers referred to as an effective peer-to-peer exchange with their colleagues (see also THEME4), may represent a demanding commitment for some. In Italy's CS8, teachers showed widespread resistance to being observed while teaching and more generally there were few cases in which teachers agreed to be observed when simply asked to do so. When mutual observation was instead explicitly supported and established as an integral part of the programme (as for example in Brazil-CS2, Colombia-CS3, Spain-CS2) teachers expressed great enthusiasm for the process.

Some teachers also pointed out that sometimes consolidated groups sharing common visions of education, along with practices of communication and interaction, might as well be subject to stagnation because inclusion of external stimuli is limited. In Spain's CS1 (see e.g. p. 68), a group of teachers from different schools with a long history of cooperation and common reflection on issues emerging from their everyday classroom practice emphasized how sharing a common approach to teaching and a consolidated relationship with academic research in education may represent a barrier to including other colleagues in the group.

RECOMMENDATION 1

Cooperation and sharing represent fundamental components in teachers' practice and professional development. Systemic elements such as pre- and in-service training, organization of work time and spaces, documentation and communication tools should be so designed as to promote a culture of cooperation and sharing among teachers in each school.

TRACES research suggests that cooperation with colleagues is precious for teachers' work. It promotes reflection on practice and therefore teachers' professional development. By creating a sense of belonging to a group with common objectives and issues, it strengthens teachers' motivation and confidence.

In working and reflecting cooperatively with their colleagues, teachers should be committed to sharing and questioning crucial elements of their practice, such as a vision of education, the role of the school in its territory and community and epistemological and methodological aspects of the pedagogy of the disciplines.

Policies should recognise cooperation and sharing as a structural part of teachers' practice and provide appropriate resources in terms of time, spaces and training.
Provision of time resources calls for a reorganization of teachers' work time as to include activities such as cooperative planning, reflection, assessment and teaching. Sharing is also promoted if teachers are encouraged to document their activities and produce materials that can be accessed and used by colleagues.

Training also plays a crucial role in promoting a culture of and nurturing competencies for cooperation and sharing. Teacher preparation and professional development programmes should include such activities as team work, mutual observation, shared planning and reflection.

Research should further investigate into the opportunities of cooperative practice and shared reflection and provide support on how to document teaching activities and produce usable materials.

The use of online community tools, although still hindered by some resistance due to the novelty of the medium, represents therefore a promising contribution to teachers' opportunities of communicating and sharing experience, reflection and materials and should be promoted. Teachers should be involved in the development of more effective and usable online community tools to be then provided to all schools.

THEME 2: Exploiting existing resources

The question of limited resources available to schools, in terms of personnel, materials, opportunities for inservice training etc. is perceived as paramount by most teachers involved in TRACES research. In the large-scale national surveys, teachers referred in particular to a higher provision of material resources, laboratorial facilities, connection to the internet as relevant factors for improving science education. TRACES research suggests that important resources exist in the school system which it is sometimes difficult to identify, acknowledge and effectively exploit.

Many teachers and groups of teachers develop rich professional knowledge through practice and in-service training. Many teachers have consolidated competencies in specific areas such as laboratorial activities, disciplinary content, pedagogical approaches, interaction with the informal sector, involvement in school- or university-based research programmes and may play the role of experts and support their colleagues' practice and professional development with limited impact on schools' budgets.

TRACES researchers found that expert teachers may contribute significantly to the development of the entire school when they take on roles of leadership in specific areas (Spain's CS1, see e.g. p. 67) or when their working time is organized in such a way as to enable them to support their colleagues, for example by advising about the design and implementation of laboratorial activities (Italy's CS7). In Italy's CS5, the entire development of a peer-to-peer training programme was put at risk when the leading teachers were forced to discontinue their commitment due to personal problems.

In Brazil's CS2, researchers found that the teachers in the school involved took up the role of leading actors in promoting innovation by making the best of the latest policy reform allowing for greater freedom in organizing classes and work around more cross-disciplinary conceptual nodes.

A relevant insight emerging from TRACES case studies involves the issue of how teachers may capitalize on their experience in classroom practice and professional development so that the experience of each individual can serve as a resource for himself and the teaching staff as a whole (see also THEME 1).

In particular, the problem of how to document experience and produce materials which are 'usable' by other colleagues and how to share these materials seems complex. According to the discussions in Italy's CS2, teachers identified the two fundamental elements for sharing and fruitful exchange of experiences in the documentation of their work and the production of usable materials, and the meetings in person in which one gets the real feeling of what people need and why certain materials might be useful for future activities.

Cooperation among teachers from different cycles seems particularly effective since competencies are often complementary. For example, teachers from the primary cycle are usually more competent on issues related to pedagogy and classroom management while teachers from the secondary cycles may be more competent in disciplinary content. TRACES researchers found that teachers practice can effectively benefit from cooperative activities such as shared planning and reflection (see e.g. Italy's CS7). In the comprehensive institute involved in Spain's CS1 (see e.g. p. 148), researchers encouraged teachers from the primary cycle to exploit the science laboratory facilities in their institute, formerly only available to secondary cycle students. The process resulted in a permanent change of the internal regulation for accessing the laboratory.

On the other hand, the opportunities available to teachers in comprehensive institutes may be missed when teachers tend to consider their students' learning along the different cycles as separated in self-consistent blocks, rather than a consistent, coherent long-term path (see e.g. Italy's CS8, p.204) or when they are not able to develop a shared vision of founding questions, such as whether the school curriculum should or should not refer to methodology besides contents (see Italy's CS1, p. 43)

RECOMMENDATION 2

A rich patrimony of experience and competencies related to science education exists in all schools and should be valued and exploited. Many teachers can be recognized as experts with specific competencies and can effectively contribute to their colleagues' practice and professional development as well as to the broader science education research debate. In particular, cooperation and sharing among teachers from different school cycles and scientific disciplines should be promoted.

Findings from TRACES' extensive interaction with schools highlight the existence of a rich patrimony of experience and competencies which can be precious for supporting further development. On the other side, teachers are not seen as the ones in charge for making experiences transferable to different contexts: a role which is most commonly appointed to scholars.

Effort should be put in making explicit, accessible and usable the pedagogical and didactic knowledge, as well as instructional materials, produced in schools through everyday practice and individual and shared reflection.

In particular, specific disciplinary and pedagogical competences developed by many experienced teachers through yearlong practice and training should be valued and exploited in supporting colleagues in their own practice and professional development.

Some teachers should be appointed specific functions in their schools, such as responsibility for the science laboratory and training and advising colleagues in developing and implementing laboratorial activities related to specific science content.
Experienced teachers should be involved as educators in teacher preparation and professional development programmes (see also THEME 4.).

The recognition of experienced teachers should not be internal to the school's teaching staff but imply a broader process involving external actors such as the local community, researchers and other experts (see also THEME 3 and 7).

Some elements of the school system also structurally contribute to providing teachers with different competencies. While primary school teachers are more extensively trained and more experienced in pedagogy, secondary teachers are more competent in content knowledge related to the different scientific disciplines. Cooperation and sharing between teachers from different school cycles and trained in the different scientific disciplines should be promoted as an effective and inexpensive strategy for exploiting existing resources for enhancing teachers' pedagogical, disciplinary and cross-disciplinary competencies.

Alongside scholars and educators from the non-formal sector, teachers should be involved as active participants in the educational research debate, to which they may contribute with specific competences and experience.

THEME 3: Cooperation between teachers and researchers

Teachers very broadly expressed great appreciation for their interaction with academic researchers. In particular they remarked in several circumstances and in different contexts the advisability of setting up stable communities of practice formed by teachers and researchers cooperating as peers so that each member, by means of active participation, provides meaningful contribution for each other's work. Some teachers (Spain, CS1, p. 152) suggested that this kind of interaction should be compulsory and regular.

In several contexts, the interaction between teachers and researchers seemed particularly effective when it involved direct participation of researchers in teachers' activities, especially classroom activities. This occurrence allowed actual exchange between the two groups, moving from a shared practice that played the role of common ground within which people were able to construct meaning. The interaction between teachers and researchers appeared less effective when these participative modes could not be established (see e.g. Italy's CS1, p. 49).

In many cases the researchers' presence played a relevant role of catalyst, facilitating reflection and sharing within the groups of teachers. In some situations, the researchers' action supported the development of potentialities which were already present in the schools but scarcely developed otherwise.

Several results from research in science education were considered hardly understandable by the side of teachers, because they too weakly refer to real situations. Sometimes research results are considered useless, because they reformulate taken-for-granted ideas in a more complex language. Actually, some teachers (Italy, CS7, p. 187; Spain, CS3, p. 138) expressed scarce interest in research results as they are ordinarily published, because they turn out scantily accessible and usable. In other cases, however, teachers appreciated the possibility of accessing literature in the field of science education through the researchers' mediation (see e.g. Spain's CS3).

Some teachers expressed a strong confidence in the way they work and in the implicit assumptions underlying their choices. On the other hand, almost all teachers, both those who feel strongly self-confident and those that do not, referred to the necessity of building large theoretical frameworks, characterized by strong keyideas, to be used as reference frameworks for planning and conducting classroom activities. These frameworks could be either autonomously outlined by groups of teachers in a school (Italy, CS7, p.183; Brazil, CS3, p.104) or elaborated by groups of teachers collaborating with researchers (Spain, CS3, p.145; Italy, CS2). According to a widespread idea, the production of such a framework should entail a rethinking of the structures of scientific disciplines in a didactic perspective.

RECOMMENDATION 3

School is the most significant place where research on learning and teaching can be developed. In order to make research sustainable and effective, teachers should have opportunities to meet and share ideas and practices with external actors, engaged in research in the field of science education. This kind of research should aim, on the one hand, at producing general frameworks of reference. On the other hand, it should aim at developing proposals feasible and compatible with forms and features of school practice.

School is the main and most significant common ground for teachers and academic researchers in science education to work together with their different expertises and sensibilities.

Actual improvements in science education can be achieved through the interaction among teachers and researchers in communities of practice, where each one – by means of active participation – provides meaningful contributions to each other's work.

Differently from teachers, academic researchers in science education devote most of their time to reflection and analysis, without practical concerns such as the management of classes, the relationship with parents etc. Therefore, they should be fit to give a relevant contribution in order to outline, along with teachers, a theoretical framework for the design and development of science education activities and assessment strategies.

This framework should be, on the one hand, general enough to guarantee that teachers will be able to use it autonomously according to their needs, interests and possibilities as well as the specificities of the contexts in which they work (see also THEME 2). On the other hand, the framework should be structured enough in order to give sense and coherence to the teaching practice.

Therefore, teachers and researchers in science education should be committed to make explicit the features of scientific knowledge (in its forms and in the way it is produced), according to the contribution those features can offer to people's cultural development and considering their relationship with the cultural background within which science education is carried out.

A mediation seems therefore necessary between science as a specialistic cultural production and educational needs. The efforts aimed at an effective mediation should provide a reshaping of science according to what and how to teach in schools. In this sense, reshaping of scientific knowledge should be a central commitment for research in science education.

This reshaping should encompass several levels. A reorganization of the structure of scientific disciplines is necessary in order to clarify the relationship among the related conceptual, formal and operational aspects. A central point concerns the possibility of recognizing how these elements comply with the way people ordinarily understand, use language and act in their everyday life. In this perspective, a special emphasis should be put on the relationship between natural language, with its rules, meanings and uses, and the same features of a scientific view, with a particular focus on the role played by mathematics.

A reconsideration of disciplinary structure should therefore necessarily take into account the way people understand and learn, so that cognitive modelling plays a relevant role as a tool for bridging between individual and culturally stabilized knowledge.

The design and the development of science education activities should be grounded in research findings on learning dynamics and cognition. Since cognitive models can – more or less implicitly, more or less naively – inform teaching strategies, efforts should be made in order to highlight the specific contributions cognitive sciences can provide with regards to issues of didactic mediation, making explicit the implications and the perspectives of the different possible approaches.

A regular interaction between teachers and academic researchers in a shared context of work and reflection can provide opportunities for taking advantage of respective contributions to the development of effective practices in science education. Results from research in science education seem to be scarcely appealing for teachers because they are often poorly accessible and usable. Teachers often remarked that research findings are hard to understand because they are too weakly referred to real situations or useless because they say what is already known in a more complex way.

Researchers interventions at school should be based on a participative cooperation model in which all actors work together as peers and decisions are taken collegially. It is important to be committed to building a common language and identifying common needs and aims.

In order to effectively impact practice, cooperation should not be limited to lecturing and training at the teachers-researchers level but include shared work in the classes, where concrete issues can be addressed and relevance of the experimented approach demonstrated.

Long-term experimentations carried out by teachers and researchers together should be promoted. This kind of research activities supports the development of meaningful educational activities based on more reliable evidence about their long-term effectiveness.

Researchers can play a role of catalyst within groups of teachers committed to shared reflection about their practice and experimentation of research-based approaches (see also THEME 2). In this case, researchers should be able to support teachers in ordinary educational contexts applying a flexible approach in which the intervention can be developed according to participants needs and interests.

Besides collaborating with single groups of teachers, researchers should also address more general issues related to educational systems (see also THEME 6). Researchers should provide contributions about the way preparation, in-service training, curricula and evaluation strategies and procedures can be coherently developed. A growing body of research suggests that a promising approach is emphasis on cross-cutting concepts and disciplinary core ideas and learning progressions across grades (see also THEME 5).

THEME 4: Teacher training

The direct and participative involvement of teachers in training programmes seemed to play a very relevant role in TRACES field actions. Actually, teachers in different contexts acknowledged a great usefulness of training activities in which they were involved in a participative form. Training sessions were particularly appreciated when they were centred on dynamics that typically develop in the ordinary practice of science teaching and learning. These activities were considered effective and motivating because they promote teachers' commitment to the development of innovative paths in science teaching.

In several contexts it emerged that the training programme can be scarcely meaningful and badly received by involved teachers if it imposed top-down. Generally, groups of teachers expressed the need of autonomously deciding forms, ways and contents of in-service training activities. The possibility of setting up training environments based on peer-to-peer interaction was broadly acknowledged as relevant.

A certain difficulty was pointed out in planning and conducting activities in science education which are structured in a flexible enough way in order to allow for a free explorative practice and a meaningful production of discourses, starting from ordinary pupils' knowledge. This difficulty was mainly expressed by primary school teachers (e.g. Italy, CS2, p.69). According to the teachers, this is related to a difficulty in managing specific disciplinary content (e.g. Italy, CS4, p. 119; CS8, p. 210). Many teachers referred to inadequate training, both pre- and in-service, as the main factor in their lack of confidence.

Some teachers expressed a considerable difficulty in managing the divergent ways pupils can adopt when they approach specific scientific content. Many teachers explicitly requested that some training activities be devoted to support and develop their capability to manage this kind of situations, in order to allow for a significant inclusion of different contributions which pupils could bring to the work sessions at school.

Some teachers attributed great relevance to training programmes which enable them to elaborate an autonomous pedagogical view in which to frame science education activities (see e.g. Colombia, CS1, p. 77). Training seemed to be more effective when teachers were able debate and re-elaborate curricular content and instructional materials (e.g. Israel, CS1, p. 22).

It seemed that useful training programmes should include elements concerning the ability of understanding the connections between what happens at school and the ways people live, understand and learn. A need for training programmes to include insights coming from social and anthropological studies emerged in several contexts both explicitly (Colombia, CS1; Argentina, CS2) and implicitly (Italy, CS7, p. 192). A need also emerged for training on elements related to cognitive issues, as well as reflections about the relationship among mathematical, scientific and linguistic knowledge. For example, teachers in Spain's CS2 (see e.g. p. 104) emphasized the value of introducing a specialist language along with the use of the related concepts in classroom activities. Other teachers (Brazil, CS1, p. 66) considered the relevance for students to autonomously produce scripts in order to reorganize inquiry-based activities. This task also seemed to improve students' linguistic skills, as it was pointed out by teachers teaching classes with significant numbers of students with migration background (e.g. Italy, CS3, p. 102).

In different contexts, a view emerged that in-service training should have the actual teachers' needs as a starting point. Therefore, the training experiences should be designed weighing and integrating in an equilibrated manner both theoretical and practical aspects (Israel, CS2, p.60), so that teachers can recognize the possibility to use, in the ordinary practice, what has been developed within the training activities (Spain, CS1, p.64). At the same time, teachers should be enabled to compare contents and forms of training experiences with their personal beliefs about science education (e.g. Brazil, CS2, p.97). Moreover, it seemed that the actual possibility of making sense of training activities lies in the fact that teachers can recognize the opportunity to explore point of views that are wider than those they usually consider, but tracing back to already consolidated knowledge and experience (see e.g. Italy, CS2, p. 73).

TRACES research suggests that training activities that reflect classroom activities in their structure are perceived as relevant by science teachers. This opinion was shared by both groups of teachers involved in the development of field actions and different actors that took part in workshops during the final conference. In particular, great relevance was attributed to training activities which actually encompass practical and laboratory work. For what regards in-service training, this was related to the fact that such activities seem to enhance teachers' confidence in managing the work with pupils (e.g. Spain, CS3, p. 147). For what regards preservice training, participant teachers pointed out that such activities enabled them to imagine themselves as teachers and project themselves in actual situations (see e.g. Brazil, CS3, p. 121).

In many cases, mutual observation and analysis of classroom activities emerged as effective tools for teacher training. These two practices seemed to enable teachers to enhance their awareness of their pupils' long-term improvements while reconsidering the short-term impression that the teaching might be ineffective (Spain, CS3, p. 103). Also, the observation of classroom sessions undertaken by experienced teachers was perceived as very useful, in that it demonstrates the effectiveness of specific approaches to instruction (Israel, CS1). Another relevant element for the training activities seemed to be the sharing among people in form of discussion, which enables trainees to have the opportunity of re-constructing in a meaningful fashion their pupils' experiences, situating their teaching in an broader frame (e.g. Colombia, CS1, p. 80).

In several cases, teachers attributed a considerable relevance to different forms of acknowledgment of their participation in in-service training, not necessarily in terms of retribution. Trainee teachers aiming at becoming

trainers seemed to develop a particular sense of effectiveness compared to other colleagues in their training group (Spain, CS1, p.63).

RECOMMENDATION 4

Teacher training as a continuous process should be mandatory. Peer-to-peer training is represent an particularly effective and economic resource and should be more extensively exploited. Training programmes should include activities related to the planning, evaluation and analysis of teaching/learning dynamics as they actually develop in the classroom.

Effective training programmes should aim at providing teachers with tools that enable them to develop their work according to a desirable profile of autonomous and responsible teacher (see also THEME 2). Training can be provided, on one hand, by colleagues, if appropriate structural conditions are guaranteed by the system. On the other hand, training should be provided by experienced trainers in science education who actively engage in ordinary work with classes in addition to lecturing.

As a continuous and long-term process, training should move from isolated, short-term, fragmentary and incoherent initiatives to become an on-going teacher and school guided process of supported reflection aimed at informing practice.

Professional development opportunities should, on the one hand, be embedded in ordinary teachers' work, and on the other, that they should be linked to real classroom practice, adapted to the purpose of addressing the specific issues of teachers involved. In this perspective, teacher professional development should become part of teachers' professional practice and therefore be mandatory.

The direct involvement of the trainers in classroom activities is an important factor in making the training more meaningful and relevant for the involved teachers. Training activities, however, should include both action and reflection on what actually happens at school, in order to provide teachers with tools usable in and compatible with real work contexts. At the same time, effective training activities should encompass sessions devoted to mutual observation and sharing of different competencies in a group of peers.

An effective training should make involve a commitment to outlining a reshaping of scientific knowledge in a pedagogical perspective (see also THEME 3). Relevant elements of a training programme should be devoted to reconsidering disciplinary content taking its epistemological implications into account and developing insights about how scientific ideas form as suggested by their historical development.

A special attention should also have to be paid to cognitive dynamics, with their implications for what concerns the pedagogical mediation and the evaluation. In this view, also the information and communication technologies should be reconsidered, taking into account their peculiarities, with regards to the way knowledge is built through their use. Their opportunities to produce specific operations and representations should be analysed in training sessions, as well as the cultural elements they embody in their working.

It also seems relevant for training to address broader issues, such as those covered in other THEMES in this analysis. Along with cognitive and epistemological elements, for example, insights from anthropological and socio-cultural studies related to teaching/learning should be an integral part of teacher preparation and inservice training.

Training should also provide teachers with tools for documenting, analysing and evaluating their activities and the teaching/learning process developed in their classes. Direct and participative involvement of teachers may also play a fundamental role in order to produce effective and motivating dynamics in training activities. Many of teachers involved in the TRACES field actions attributed great relevance – in terms of effectiveness – to participative training environments.

Training contexts should be characterized as situations where teachers are directly involved and participate as active subjects, confronting with actual dynamics typical of teaching/learning processes and dealing with the specificity of science knowledge, as well as with the contribution it can give to the pupils' formation.

Moreover, another factor emerging as relevant involves engaging teachers in situations that are similar – for treated contents and educational strategies – to those they are expected to create with their students. The idea is that the way training is developed should reflect the way one thinks science and mathematics have to be taught in the classroom.

In this view, training sessions should encompass a set of activities that involve theoretical framing, laboratory experimentation, multi-representation and explanation of what happens, which are mutually intertwined and not hierarchically structured.
Nevertheless, training activities have to necessarily include elements devoted to develop abilities and sensibilities concerning the meta-cognitive analysis, playing a fundamental role in the managing of groups engaged in learning experiences.

Many teachers in the TRACES field actions highlighted a difficulty in relating to students' divergent ways of thinking and approaching scientific problems. Training programmes may address this issue explicitly through the use of cultural tools – as provided by research and reflection in several fields - as lenses which enable to reconsider and interpret teaching strategies and learning dynamics.

Policies establishing in-service training as mandatory will only be effective if they are accompanied by an actual enhancement of the training opportunities available. Moreover, enabling teachers to autonomously determine their in-service training path and negotiating the content and structure of the training programmes they undertake can contribute to address the issue of episodic, fragmentary and incoherent training experiences as identified by research on "traditional" in-service training.

The actual possibility for teachers to make sense of science education activities and strategies as they are suggested by research seems to lie in the grade of proximity between the promoted pedagogy and the way teachers intend and carry out their work, as well as their disciplinary and pedagogical knowledge and expertise. This suggests that effective training activities should have their starting point in the way participants actually work and aim at offering a progressively enlarged perspective. Teachers involved in field actions based on this model expressed higher confidence in their professional development through the training and sense of relevance of the training to their teaching practice.

THEME 5: Relationship between local and central

Stakeholders involved in the TRACES research programme broadly expressed the need for a larger involvement of the different actors, at the local level, in open debates about pedagogical issues concerning science education and related specific actions to be undertaken. This position appeared to stand out against initiatives imposed top-down, which are perceived as inadequate with regards to taking local needs into account.

In several contexts, the relevance of socio-cultural issues is so strong that it significantly constraints teachers' choices, as well as those of entire schools, for what concerns both the implemented curriculum and pedagogical and instructional aspects of everyday practice. This emerged in both European urban, middle/lowincome contexts (Italy, CS7; CS8) and, in Latin-American contexts with limited access to resources (Argentina, CS2) or exposed to conditions of environmental degradation (Colombia, CS3).

It was very broadly requested that the structure of curricula and related evaluation criteria should be designed in order guarantee sufficient flexibility for teachers to be able to adapt them to the specific needs of their local contexts. Teachers in our case studies suggested, in particular, that standardized tests should rather be aimed

at providing a picture of the global situation of a school, or of a school system, than being used for students' assessment (see e.g. Italy, CS7, p. 182). Furthermore, some teachers pointed out how the introduction of standardized tests forces to implement a broader curriculum in the attempt of covering all subjects included in the national curriculum increasing the tendency to cover too many subjects in scarce depth (see e.g. Israel, CS2, p. 60), a tendency stigmatized in research literature as the mile-wide, inch-deep curriculum.

In some cases, evident tensions and divergences were recognized between teachers seeing education as aimed at the development of critical thinking and responsible citizenship, and policy makers interested in fostering the development specific skills aimed at guaranteeing productivity and economic competitiveness of the nation (Israel, CS3, p. 81). In the same way, tension were highlighted (Colombia, CS3, p. 165) between general ideas about science education as they promoted by research and national curricula and the specific contextual needs as identified by the teachers in their everyday practice.

In some case studies, high school students seemed scarcely involved in a debate concerning the social role played by science education. In some contexts, students picked out basic competences in mathematics and science – those covered in primary school - as the only ones related to their everyday life (e.g. Italy, CS5). At the same time, however, they seemed scarcely interested in the learning in that area. On the contrary, in situations in which students were involved in a debate on the social role of science education, students were participated more actively in their learning at school (e.g. Colombia, CS4; Argentina, CS3).

RECOMMENDATION 5

Curricula and evaluation strategies and tools should be designed in order to enable teachers to take local specificities into account. Curricula should be flexible enough to be adaptable to needs related to local educational contexts. Standardised tests should be aimed mainly at gathering data that support schools in evaluating how their students' performance are related to the national standards and at revising general educational policies.

A structural tension exists in the school system between the central and the local dimension. In their everyday practice, science teachers are committed to finding an effective compromise between taking their students' specific needs and interests into account and complying with national indications about the contents and pedagogy in the science curriculum. Implemented curricula in each specific class should not neglect local factors such as student families' and the broader community's socio-cultural specificities at each time in their historical development.

Another structural tension between the central and local dimension is related to the gap between science education research and actual teaching practice. Researchers should commit to the development of an intercultural approach to science teaching, proposing a vision of scientific knowledge which does not discredit, invade or discriminate the local culture. It seems furthermore important that teachers be involved in this process in order for the research to have an actual impact on practice.

In order to manage the integration of the central and local dimension, schools (and teachers) need to enjoy a sufficient degree of flexibility in designing and programming educational activities, in choosing teaching approaches and methodologies. Curricula should be designed in order to guarantee such flexibility, identifying key learning objectives that are general enough to be adaptable to local needs. A promising line of development in this direction, as suggested by research, is to base national curricula on disciplinary core ideas and interdisciplinary crosscutting concepts to be addressed along long-term learning progressions across all grades.

Assessment strategies significantly inform educational strategies adopted in schools. The use of standardised tests to assess students' performances may represent a further barrier to the integration of the central and local dimension in science education. Rather of being used as official assessment tools, standardised test

should be intended to provide schools with general indications highlighting possible learning difficulties of their students. Low performance in the tests should result in enhanced support offered to the schools in terms of material resources and teaching staff.

Standardized tests can be used with the aim to provide schools an tool for evaluating effectiveness, issues, barriers and devise strategies. Self-evaluation activities may promote teachers' sense of ownership and responsibility in their work in agreement with a broader vision of autonomy as addressed in other THEMES in this analysis.

Teachers should be granted a more active role in the debate determining the choices made at the central level about the structure of curricula and assessment tests. A possible strategy to pursue this aim is the formation of consulting commission/boards involving teachers together with other relevant actors (principals, supervisors, curriculum developers, researchers, school administrators).

THEME 6: Long-term sustainability

TRACES research suggests that initiatives promoting innovation and experimentation in science education are more likely to involve entire schools and large numbers of teachers when they are sustained by those responsible for educational policies because they are perceived as structural by the teachers (see e.g. Israel, CS3, p.84). In the cases in which this institutional support is lacking, the results obtained by this kind of initiatives seemed very limited.

Particularly favourable circumstances for the development of effective innovation initiatives emerged in those cases (Argentina, CS1, 2, 3) where educational authorities were committed to follow and coordinate the development of the actions through the work of supervisors having a school teaching background.

On the contrary, national initiatives perceived by teachers as unsuccessful were often characterized (Spain, CS1, p. 67; Italy, CS7, p. 178 and CS8, p. 203) by an initial enthusiastic impulse not followed by the needed institutional support promoting processes of cooperation among schools and with other actors involved in educational experimentation, such as researchers or educators.

In order to implement initiatives aimed at promoting innovation of science teaching in their schools, school principals highlighted a need for adequate financial support and the actual possibility of suitably reorganizing teachers' timetables (Israel, CS2, p. 60). In fact, significant experiences were developed in those cases in which school administrators provided teachers with an actual recognition of the workload related to participation in special initiatives (Spain, CS1, p. 51). These enabled them to grant teachers a longer-term basis in the implementation of the initiatives, incorporating the innovation activities in teachers' ordinary work-plan and providing specific professional development courses connected to the proposed experimentations.

Producing documentation materials about the classroom activities was recognized by many teachers, including those involved in training courses (Colombia, CS2, p. 97), as a very meaningful way of setting up a shared reflection and evaluation of their work. Nevertheless, difficulties emerged concerning the access to materials produced and circulation of the related reflections made by colleagues, even in those cases in which this practice seemed to be well-established among teachers (Italy, CS2, p. 67).

In some cases (Spain, CS3, p. 137), a difficulty emerged among the teachers to inscribe their work within a more general reference framework shared with their colleagues, going in the direction of defining a vertical curriculum covering their students' entire school path. Even in those cases (Italy, CS1 and CS8) in which the development of a vertical curriculum (including grades from 1 to 8) was sustained by official indications, teachers expressed their difficulty in sharing a common framework with colleagues teaching in different school grades.

Some case studies suggest that when teachers recognize themselves as intellectuals having full responsibility in choosing the cultural directions framing their teaching practice they are more likely to set up significant educative experiences (Colombia, CS1, p. 62). These of teachers expressed the need to share with their colleagues the construction of a theoretical framework for their practice, claiming the need for a wide decisional freedom based on their awareness of the socio-cultural context in which they operate (Italy, CS7, p. 138) and on their capacity to link classroom activities with the spontaneous knowledge built by their students in their everyday life (Colombia, CS4, p. 209).

RECOMMENDATION 6

Schools should be enabled to autonomously develop educational experiences that are shared within the school itself in a community dimension, giving continuity to the educational choices made and making the school capable to consider and exploit the opportunities of support offered by the school system and the interaction with external actors.

Teachers' self-confidence in the possibility of autonomously undertaking paths and experiences in science education which are meaningful for their students (and for the teachers themselves) is key success factor in effective science teaching. Teachers' work should be framed according to general, fundamental guidelines which leaving teachers free to autonomously develop specific educational paths in their classes. Teachers should be provided adequate tools (disciplinary knowledge, expertise in planning, evaluation strategies and criteria) to be able to effectively pursue their educational objectives and be flexible enough in undertaking their strategies. Sharing this approach to teaching practice in a community dimension within the school can promote a meaningful process of continuous revision of the teaching strategies.

A prerequisite for any widespread improvement of science teaching is the establishment of a stronger coherence among the fundamental elements of the school system: teacher preparation, curricula, continuous professional development and evaluation strategies.

A carefully balanced science curriculum combining core disciplinary ideas with the broader content and everyday experience may represent a general framework for guiding the development of school teaching. This also offers teachers a common ground for continuous dialogue about scientific ideas, disciplinary aspects and methodological issues with a strict connection to their actual practice. The science curriculum should be flexible enough to enable teachers to adapt it to the needs emerging from this process of reflection about their work.

Schools should be strongly committed to producing materials documenting the educational experiences undertaken by their teachers. Documentation should be shared among the teachers and continually revised and reused in the classes. This also provides criteria on the form and contents of "usable" documentation. Documentation should explicitly refer to the framework within the activities have been developed and to the criteria used to evaluate them.

The continuity of the educational choices made in each school is can be supported by appointing some teachers with specific institutional roles in coordinating the sharing of documentation materials. This also enhances teachers' opportunities to work as a community and facilitates the integration of new teachers joining the school staff in the community.

The construction of a community dimension within the school also enhances teachers' ability to identify opportunities for external support (in-service training, extracurricular activities, classroom experimentations) according to what best suites their professional development needs. This approach also supports the interaction between the school and the broader school system and external actors. The interaction should be mediated on the small-scale level by institutional figures such as supervisors in order to exploit resources available at the local level and promote the development of collaborations within local networks of schools and

other institutions (universities, teacher training institutes, science centres and museums, other associations and centres involved in science education).

THEME 7: Relationship between school and society

In a number of contexts, a lack of active involvement in the development of the learning experience by the side of students (especially those in higher grades) emerged. Students often perceive scarce relevance in both the content of school topics and the way school activities are carried out. Italian 12-graders (Italy, CS5, p. 141) manifested rather naïve visions of the social function of science literacy, assigning actual relevance to elementary competences and skills only, while perceiving more complex disciplinary contents as part of a selfreferential scholastic knowledge difficult to relate to everyday experience.

Many teachers highlighted (see e.g. Brazil, CS1, p. 63) that the effectiveness of the teaching/learning process is enhanced when the formulation of problems and questions moves from a teacher-centred to a studentcentred approach. For these teachers, this implied explicitly discussing with the students the relevance of the topics proposed as connected to the actual socio-cultural context they are part of.

This approach seems to be effective in that it promotes students' active involvement and sense of ownership of the scientific knowledge they are expected to develop. Also, it seems to enable students to develop a sense of responsibility towards the evolution of their knowledge and to consequently recognize themselves as actors actively participating in the life of their community (see Colombia, CS4, p. 20). This kind of perception about school science is strongly contrasting with the ideas expressed by the abovementioned Italian students (Italy, CS5, p. 141) who seemed to perceive scientific knowledge as elitist and socially discriminating as a consequence of the difficulty in accessing its specialistic language.

In some case studies (in particular two case studies involving schools based in middle-class areas of European cities, see Italy, CS6, p. 159; Spain, CS3, p. 120), students' families attention towards school activities was perceived by teachers as an undue pressure interfering with their work. Teachers remarked that they sometimes feel obliged to make particular educational choices in order to meet parents' expectations. In other cases, teachers mentioned how their will to keep an autonomous way of managing school activities can cause conflict with the parents. On the contrary, direct involvement of students' families in the educational experimentations carried out at school (Spain, CS2, p. 115) seemed to promote parents' recognition of teachers' work parents and teachers' awareness of the relevance of parents' involvement. In this specific case, the relationship between teachers and parents was also enriched and mediated by the presence of external actors (university researchers) directly involved in the experimentation activities.

Teachers, principals and other school personnel in suburban schools (see e.g. Italy, CS7, p. 180, CS8, p. 211) seemed to feel a responsibility to support what one might call social promotion of the local community and it seemed that the relationship with families is driven by this perspective. These actors attribute particular relevance to the involvement of families in supporting children in their learning experiences and consider school and family as two interacting parts of the same system (Italy, CS7, p. 185).

In a perspective in which school education – and science education in particular – is considered as a means of promoting social transformation (Italy, CS7, p. 178; Colombia, CS1, p. 119), teachers seemed to feel that they have to be strongly invested with the responsibility of their social function, able of mediating among different needs (ranging from the pedagogical to the political ones) and of actively participating to the life of their community.

Active involvement of the local community has been recognized as even more relevant in those contexts (e.g. Argentine, CS1, p. 28 et seq.; Colombia, CS1, p. 113) in which the local community's cultural identity is specific

and distant (even linguistically in Argentine's CS1) from the one on which school teaching is based (Argentine teachers called it the "national culture").

In case studies carried out in schools based in indigenous communities in Latin American countries, it seemed particularly relevant to design and develop science teaching/learning experiences whose structure was compatible or otherwise interrelated with the cultural perspectives, the practices, the language of the local community. On one hand, it seemed important to recognize the way these communities consider people as an integral part of their environment. On the other hand, as long as these communities are not characterized by a strong differentiation of productive activities, insisting on the differentiation of areas of knowledge seemed to make little sense.

Case studies carried out in some Latin American countries (Argentine CS1, CS2, CS3; Colombia, CS1) highlighted that an effective integration of the school with the local community takes place when the school is able to interpret and account for the needs of the community. In some of these cases, science education activities were focused on addressing of local material needs such as the access to energy sources, the purification of water in order to make it drinkable, the protection of the environment, the development of a balanced diet. This approach to science education (Colombia, CS4, p.207) seems to make the teaching/learning experience particularly meaningful in that it addresses practical problems that are relevant to the community and while covering important science content it highlights its connection with the everyday life of the community.

Even in cases in which the material needs of the local community are less urgent, teachers emphasized the relevance of linking the way the educational experience is structured with the local socio-cultural context (see e.g. Italy, CS7, p. 181). These teachers highlighted that scientific disciplines – with their peculiar interrelation between operative and explanatory aspects – offer a unique opportunity for personal development to those students who have scarce access to meaningful learning experiences due to their socio-cultural background.

As we emphasized as a preliminary remark to the TRACES research programme, research findings suggest that gender has a crucial role in determining different attitudes and learning styles and that science learning is a typical gender role–stereotyped domain in which boys and girls tend to be strongly conditioned by their selfperception with regards to scientific competences and skills.

TRACES' surveys addressed the problem with three specific questions included in the teacher questionnaire in all partner countries[3]. We asked teachers if they experience differences of interests in boys and girls towards different scientific themes or engagement in different types of activities.

A very evident result is that the issue is generally underestimated by the majority of teachers questioned. Most of respondents said that they do not notice difference among their male and female students and their comments suggest that taking difference into account is perceived as a kind of discrimination. The attitude perceived as "correct" seems to be treating all students as they were the same, the classroom as a whole, as if this would preserve equity.

Similar findings emerge from case studies. In Italy's CS1, CS6, CS7 and CS8 specific discussion groups were devoted to gender-related issues in science education. In all these cases, the topic of gender difference was the most controversial among all workgroup's discussions. There was an evident resistance to address the topic. When discussion did start, however, teachers had much to say about differences they notice between boys and girls.

[3] With the exception of Spain.

RECOMMENDATION 7

Actors playing a relevant role in their community should be involved in a debate about the aims of science education. Societal and local community issues should be taken into account and inform science teaching.

Discussion about curricula, teaching methodologies, assessment strategies and more generally about priorities in science education, including its nature and social role, should be part of an enlarged and open debate involving teachers along with a number of other stakeholders. The debate should place particular emphasis on issues that are related to cultural specificities of local communities (e.g. different views of the world, perceptions of the relationship with the surrounding environment, organisations of material production).

A possible strategy to promote this debate is the construction at both the local and central level of consulting boards/commissions involving teachers, researchers, students' families, school principals and administrators, leading cultural actors in the local communities, people involved in the productive activities, educators, experts in humanities and arts.

Initiatives of this kind can also promote teachers' sense of being recognized and supported in their work and reduce the distance between general educational programmes designed by ministries and national boards of experts and actual teaching practice.

Schools can act as a special context in which relevant societal issue (e.g. waste management, conservation of the environment and pollution) are discussed with a number of different actors (e.g. teachers, citizens, professionals, scientists, administrators). Schools can be the space where the unique contribution coming from an educational perspective can fuel public debate in which not only students' families but also the broader community is involved.

At the local level, it would be specially relevant for teachers, students' families and the broader local community to share a common vision of school and (science) education. Schools should share with the local community the responsibility in pupils' learning process (*co-responsibility*).

Schools should see themselves as belonging to the community and promote this vision by taking the needs of the community into account and involving the community in its activities and decision making processes (*ownership*).

Schools should make it explicit that the knowledge taught in the classes is not disconnected from the students' and the community's everyday experience and culture and that this knowledge is usable, meaningful, relevant to the life of the community (*relevance*).

People from the local community can be involved in the planning of the school activities and invited in the classrooms to talk about science topics in terms of their experience and expertise. This also supports the connection between school learning and the local cultural traditions and with the local environments and its transformations.

Special educational activities should be organized to involve both students and parents. Particularly relevance can have the implementation of activities in which mixed groups of students from different grades, teachers and parents work together focussing on issues from their everyday life experience. End of course sessions can be organised, in which students present their parents about what they did during the course and their learning process.

Science and mathematics education activities should be structured in order to overcome the possible lack of significant stimuli that characterize students' everyday experience, providing students with opportunities to make sense of their experiences. Special emphasis should be given to operative explorations and problem solving with regards to fundamental science and mathematics concepts.

APPENDIX B – REPORT OF THE INSTEM ITALIAN WORKSHOP

The first Italian national workshop on the impact and dissemination of science education research and development programmes was held in Naples on December 12, 2013.

Researchers in science education, expert teachers - some of whom involved in numerous national and international research and development projects - a museum practitioner and a school principal were involved. Some of the teachers are involved at various levels in the school and science department management. Two of the teachers are long-term members of teachers and educators associations (National Science Teacher Association and Educational Cooperation Movement). Many of the partipants have been involved in in-service training, both as learners and educators. A detailed list of participants is presented below.

Participants

Francesco Cuomo	Researcher science education
Bruno Fabbrocino	Secondary school teacher
Guido Di Lorenzo	Secondary school teacher
Emilio Balzano	Researcher science education
Olga Mautone	Primary school teacher
Colomba Punzo	Principal - Primary school
Anna Merinio	Researcher science education
Giovanna Mendella	Secondary school teacher
Franco Di Liberto	Researcher physics and science education
Rossella Parente	Education section – Science Centre Città della Scienza
Giulia Forni	Secondary school teacher - Fibonacci project
Marco Serpico	Researcher science education
Ciro Minichini	Researcher science education
Marco Marino	Upper secondary school teacher

Participants identified some of the issues connected to the impact of research and development programmes on school practice in the short and long term.

They referred to programmes related to European projects, national and regional programmes linked to EU funding (e.g. PON: National Operational Programmes, which are funded through EU Structural and Cohesion Funds) and to R&D programmes in general.

The main emerging issue is a lack of coherence and coordination in the various programmes. Practitioners have the feeling that one often starts from scratch in every novel programme and that there is no 'history' of the work done. In other words, the work done does not remain as a lively patrimony of the school or group of teachers involved in the original programme. This does not enable practitioners to build upon work done and progress and represent a significant waste of resources.
Another problem is that programmes are seldom evaluated against their impact in terms of change in teachers practice and students' learning. This puts all existing initiatives on the same level and leads to a process of bureaucratisation in the distribution of funds and the acknowledgement of good practice. This also prevents from being able to provide incentives for teachers that are 'doing a good job.' It also allows for ordinary, not effective practice to be preserved.

Participants agreed that it is necessary to establish organs of control, evaluation and support and that the school should not be left alone with the responsibility of good education. In particular, there was consensus that the university (researchers in science education) should be involved in the system of teachers' continuous professional development and the organization of research and development programmes. The existence of such organs could also guarantee coherence among programmes and provide research-based support.

More in general, there was broad agreement about the fact that teaching is a reflective profession and that the work done in the classroom should be seen as one part of a more complex set of activities. In order for teachers to develop in their profession, exchange with external experts (which also includes colleagues) is crucial. As some participants noted, indeed, the great majority of teachers think that they are doing their job excellently and they might just as well keep thinking so for their whole career if their activity is limited to working 'behind a closed door' with their students only.

For what regards the implementation of programmes in particular, participants agreed that working at two levels is crucial. These involve a level at which teachers work with the external experts in the classroom - that is, a real-life educational context - and a level at which teachers and external experts work without students and discuss and reflect about the real-life issues emerging from the classroom context. The model of actionresearch was referred to as very effective.

An important point seemed to be that the problem of effective school education should be approached in its complexity. Promoting Inquiry-Based methods *per se* might be meaningless if other significant factors are not taken into account. For example, working with groups of students from different classes or without involving all the teachers of the participating classes might result in very limited impact beyond the implementation of the programme. These actions might leave no trace in the school practice after the end of the programme.

Some participants pointed out that another issue is the connection between everyday practice in the classroom and the policy makers and other institutional figures with decisional power. They said that often these figures are not aware of good practice and effective projects that take place 'behind closed doors' in the classrooms and that in many cases they are not even competent in educational matters. There exists the need of upstream communication from the school to the institutional level. This could be mediated by representative boards. Also for what regards actions related to EU projects a closer relation with representatives of the institutions (e.g. Ministry) at the national level is needed. The teacher involved in Fibonacci referred to the example of *La main à la pâte* as good practice with regards to this issue.

Participants broadly agreed that in order to have a serious impact systemic actions are needed that involve teacher in-service training, promoting sharing and discussion of the implemented programmes, enhanced cooperation between teachers within the school and networks of school, a stronger link between school and experts from university (researchers in education) and other providers of education.

One of the measures proposed for enhancing the impact at a systemic level is a better exploitation of existing resources. A broad spectrum of expertise exists within teachers in service: educational, artistic, technical, relational, cultural etc. Strategies should be developed in order to identify, acknowledge and organise these experts in order to make the best of their competencies and make them available to support colleagues in their

school and in networks of schools. Again, it seems that a mediating organ is necessary (e.g. a resource centre). These organs should probably be established on a regional level.

For some participants, the issue of the relationship between the school and the local community seemed to play an important role in terms of the impact of the actions. Bringing the work done at school outside to the local community (e.g. with exhibitions or science fairs etc.) enhances students' and teachers' motivation and establish a dialogue with the outside that promotes questioning consolidated teaching practice.
One last focus of the discussion was about the role that students' needs, interests and inclinations should have in the teaching/learning process. In particular, the finding from the Instem state-of-the-art report was presented according to which, the voice of students is absent from most research and development projects.

While there seemed to be agreement that it is important to listen to students thoughts, the question of how to make the best of it remained unanswered. What should the teacher do if the students say 'I don't like doing homework' or 'This part of the lesson is boring' or 'That activity was fun'? Participants questioned if for an activity to be 'fun' or 'interesting' for the students is a measure of how 'good' and/or effective that activity is. Some participants pointed out that some of the activities that actually produce long-term learning might as well be those that are the most exhausting and unpleasant.

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