Inspiring Science Learning: Designing the Science Classroom of the Future

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Abstract. *Powerful methods for scaling-up and transferring pilot implementations and for evolving the public's conceptions of learning and schooling are essential to take full advantage of the opportunities ICTs pose. This work describes what may be its key contribution to the evolution of schools innovation and improvement: a new approach to stimulating, incubating, and accelerating innovation, which is strongly driven by users' needs. The aim of this work is a) to capture what we know so far about the process of encouraging schools to become more innovative b) to describe the Discovery Space Innovation Model which is built upon these understandings and c) to describe the practical programme of work which utilizes this model. Taking advantage from the current reform efforts in science and mathematics education in many European countries and the implementation of some major re-schooling initiatives, our aim is to develop an innovative science and mathematics learning environment, which integrates modern technologies with the aim to create an open technology-enhanced classroom that builds on the strengths of formal and informal teaching and learning strategies in ways that can support learning of all individual students. This environment is embedded with interactive learning artifacts and assessment tools. 100 such classrooms have been set in operation in the most innovative schools in Europe. If we want a powerful innovative culture in schools which is self-sustaining we have to empower system-aware practitioners, working ever more closely with the service users, to create it. And to avoid simply creating interesting but isolated experiments, we have to design in collaborative ways of learning and enquiry between professionals – a "pull" rather than "push" approach.*

Keywords. Advanced Technologies, Practitioner Led Innovation, Science Education.

1. Introduction

The Information and Knowledge Society has emerged as a result of technological advancements of the World Wide Web, the Internet and mobile communications over the last two decades. These technological developments have had; and still have direct impact to every aspect of our personal and social life, thus changing the way we communicate, collaborate, work and learn. Europe has been a world driving force when it comes to these technological developments, however, in many cases European Member States have fall behind in adopting the necessary societal re-organisational changes needed in government, education, health care and cultural preservation. This can be a critical issue for the future of European Union and the future of its Member States within the complex global challenges of the 21st Century.

When it comes to the field of education, this lack of social innovation becomes even more troubling, due to the fact that failing to "re-engineer" our national and European educational systems, effects significantly all other areas of social and economical development, jeopardising Europe's position in the global knowledge-based society. Indeed, Education seems to be a social activity still struggling to improve up to the societal anticipated expectations. Especially, schools appear to remain almost unchanged for the most part despite numerous efforts and investments in technology, teachers' training and infrastructure. Yet, the way we organise schooling and provide education remains basically the same. To put it in another way: "we still educate our students based on an agricultural timetable, in an industrial setting, yet telling students and teachers they live in a digital age".

During the past years, several reasons have been identified separately as possible distractions in aligning schools operations and results to the ones anticipated by the 21st Century Societies. The most highlighted ones being: lack of funds, not enough computers in the classroom, little interest from students and parents, out of date teaching practices, poorly trained teachers, and even a fundamentally flawed way to measure performance at schools.

Many national and European initiatives have been undertaken to tackle these issues separately. Yet, the improvement has been marginal, if any at all. We believe that a holistic approach to the re-organisation of Schooling is needed, rather than sporadic and isolated efforts. To this end, many different organisations with high quality and unique expertise in their field have decided to join forces in a European effort to propose a scientifically grounded, technological sustainable and organisationally disruptive plan for the Technology-enhanced Classroom of the Future that will give to all parties involved in schooling a motivation for change. This is our Discovery Space.

2. Supporting and improving educational practices in science and mathematics education

The publication of the "Science Education Now: A renewed Pedagogy for the Future of Europe" report [1] brought science and mathematics education to the top of educational goals of the member states (following similar actions in US in 1996 [2], [3]). The authors argue that school science teaching needs to become more engaging, based on inquiry based and problem solving methods and designed to meet the interests of young people. According to the report, the origins of the alarming decline in young people's interest for key science studies and mathematics can be found, among other causes, in the old fashioned way science is taught at schools. Although the crucial role of positive contacts with science at early stage in the subsequent formation of attitudes toward science is identified [4], traditional formal science education too often stifles this interest and, therefore, may negatively interact with the development of adolescents' attitudes towards learning science. Kinchin [5] pointed out that the tension created between objectivism (the objective teacher-centered pedagogy) and constructivism (the constructive and student-centered pedagogy) represents a crucial classroom issue to influence teaching and learning. The TIMSS (Third International Mathematics and Science Study) 2003 International Science Report [6] specifically documented that internationally, the three most predominant activities accounting for 57 percent of class time were teacher lecture (24%), teacher guided student practice (19%), and students working on problems on their own (14%) in science classes in the European countries participating in the study.

Therefore, it appears that the current science classroom learning environment is often a mixture of divergent pedagogies and diverse students' orientations or preferences [7], [8]. The fact is that there is a major mismatch between opportunity and action in most education systems today. It revolves around what is meant by "science education," a term that is incorrectly defined in current usage. Rather than learning how to think scientifically, students are generally being told about science and asked to remember facts [9]. This disturbing situation must be corrected if science education is to have any hope of taking its proper place as an essential part of the education of students everywhere.

In addition to the aforementioned issues, science learning environment (classroom and lab) seems to have not gone through any significant changes for the past decades. Recent research on learning and instruction has substantially advanced our understanding of the processes of knowledge and skill acquisition [10]. However, school practices have not been innovated and improved in ways that reflect this progress in the development of a theory of learning from instruction. School practices in a realistic sense are cantered on school learning environment. It is generally recognized among practitioners that our school science learning environment has neither been innovated nor reformed to reflect these new knowledge on learning and teaching. Moreover, modern technologies beyond just the use of computers and internet in the school have not fully integrated/incorporated in current science learning environment.

According to the recent report "Science Education in Europe: Critical Reflections" [11] the deeper problem in science education is one of fundamental purpose. Schools, the authors argue, have never provided a satisfactory education in sciences for the majority. Now the evidence is that it is failing in its original purpose, to provide a route into science for future scientists. The challenge therefore, is to reimagine science education: to consider how it can be made fit for the modern world and how it can meet the needs of all students; those who will go on to work in scientific and technical subjects, and those who will not [12]

In this framework the classroom of the future should provide more challenging, authentic and higher-order learning experiences, more opportunities for students to participate into scientific practices and task embedded in social interaction using the discourse of science and work with scientific representations and tools. It should enrich and transform the students' concepts and initial ideas. These ideas could be both resources and barriers to emerging ideas. The classroom of the future should offer opportunities for teaching tailored to the students' particular needs while it should provide continuous measures of competence, integral to the learning process that can help teachers work more effectively with individuals and leave a record of competence that is compelling to students.

3. Introduce meaningful ICT-based innovation for quality learning and teaching

The classroom of the future features a collection of interconnected e-systems and Web-enabled services to facilitate teaching, learning and assessment. All these new systems will require interfacing with key existing legacy systems that are characterized by different organizational structures. Creating an IT infrastructure plan for the school of the future isn't just about plugging in the latest and greatest—it's about balancing competing forces. Educators and technologists need to reach for the possibilities of the future, plan for the realities of the present, and account for limitations created by the past—all at the same time. To our view three complementary interfaces shape the technological infrastructure of the science and mathematics classroom of the future:

The familiar "world to the desk top" interface, providing access to distant experts and archives (see Figure 1), enabling collaborations, mentoring relationships, and virtual communities-of practice. This interface is evolving through initiatives such as Web 2.0. The work focuses on the support of learning communities where teachers and learners are helping each other, or work together on certain problems. In order to monitor, analyze and support those learning communities we need to implement tools which capture usage and interaction. We also need personal and digital agents that help to build up a learning context based on content in order to support teachers and students.

Figure 1. The Discovery Space Observatory provides access to a global network of robotic telescopes and supplies free resources for science and mathematics education.

Interfaces for "ubiquitous computing", in which portable wireless devices infuse virtual resources as we move through the real world [13]. The early stages of "augmented reality" interfaces are characterized by research on the role of "smart objects" and "intelligent contexts" in learning and doing. Those interfaces are intended to provide the freedom to learn "on site" – get into a real problem context and learn on virtual data. Therefore we need mixed reality cross platform devices, to create interfaces that seem to inhabit the users' environment. Those tools should be seamlessly integrated into the users' world. The interfaces should be light weight and least intrusive. The users have to be able to interact within their augmented environment in a most possible intuitive way. In order to create such a ubiquitous environment interfaces should be available at any time and any place where the user can be. Thus one has to build on mobile devices and visible (e.g. QR-Tags, Semacode) and ubiquitous tracking techniques, such as GPS or NFC (near field communication), inertial tracking and a complementary computer vision tracking. One major aspect of those devices is interactivity that allows users intuitive interaction.

Figure 2. Kick life into the Classroom with the Lab of Tomorrow System: Playing with a "smart" ball with embedded sensors, gathering and manipulating experimental data of real life activities.

Immersive and multi-user virtual environments interfaces, in which users and participants' avatars interact with computer based agents and digital artifacts in virtual contexts. The initial stages of studies on shared virtual environments are characterized by advances in Internet games and work in virtual and augmented reality. In order to implement "Virtual Labs" and multi user environments we demand a VR interface, an underlying context system, a high bandwidth network communication, as well as a hypermedia database. The most important part of a virtual environment is the interface through which users are able to enter the virtual world. Immersion plays a key role, thus all senses need to be stimulated properly. Moreover, it is fundamental for the effect of immersion that the system should behave in a way the user expects it to behave. This is, interaction has to be intuitive, user tracking should be accurate, this is, the system output should be realistic if necessary.

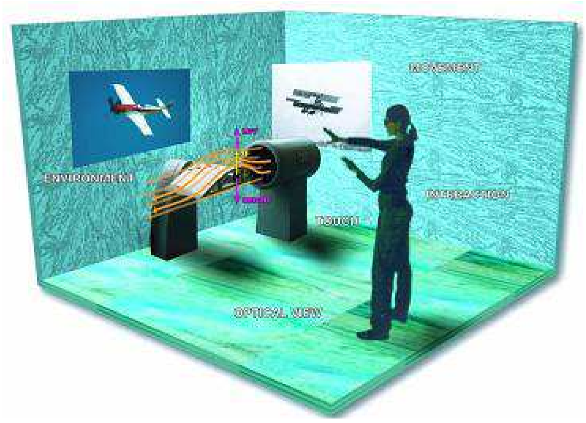

Figure 3. Visualizing the invisible using the CONNECT system: The visualization of natural phenomena could support the conceptual change.

Immersive interfaces can foster educational experiences that drawn on a powerful pedagogy: contextualized learning. Situated learning requires authentic contexts, activities and assessment coupled with guidance from expert modeling, mentoring and "legitimate peripheral participation" [14].

The technologies in this type of innovative classroom should be intelligent, interactive, individualized and integrated as the following: (1) intelligent: the classroom technology should be highly context-aware and adaptively support tasks that originally require excessive human interventions; (2) interactive: the classroom technology should facilitate interactions between the teacher and the students; (3) individualized: the classroom technology should react differently in accordance to individual user; and (4) integrated: the classroom technologies should be integrated as one system instead of many separate systems.

Technologically-based applications could effectively support the pedagogical requirements for the future science and mathematics classroom, as they were described in the previous paragraphs. Moreover, research has demonstrated empirically the effectiveness of such applications. The question is why has this potential not been realized? Several reasons are very clear: Current schools and classrooms are not designed in ways that can utilize the potential of technology; there is lack of appropriate preparation of teachers in the use of technology both at the pre-service and in-service levels leading to anxiety and low motivation to integrate technology in classes.

4. Understand and managing underlying change process

Although most of the European educational systems remain highly centralized, ICT policy implementation remains optional and allows for substantial discretion to the implementers, and for a "backward approach" leading to goal and role definitions in the field. In the light of such open-ended and general ICT policies practitioners at the micro level and the communities of implementation they generate as a response to ICT policy can be proved critical in ICT integration into the system. Our work aims to enhance the role of such communities. An important concept underlying the proposed approach is the notion of the community of implementation, which is regarded as a type of community of practice. Within our research work in particular, communities of implementation are regarded as self-reproducing, and evolving entities emerging within the school settings as a response to an externally developed policy. Various authors emphasize the importance of communities of practice for organizations [15], [16] and therefore communities of implementation are considered as a purposeful strategy for spreading innovations. For teachers, innovation is a high risk activity and the incentives are few [17]. In a system where the centre has been the innovator, practitioner compliance understandably becomes the habit. The dynamic of change in education in Europe has been described in terms of a set of shifts, first, from "uninformed prescription" (in the 1980s); to "informed prescription"; then towards practitioner-led change [18]. This last was seen as the key to self-sustaining, rapid improvement. It is within this context, that our work aims to take forward the agenda of practitioner-led change at a European level. This work describes what may be its key contribution to the evolution of schools innovation and improvement: a new approach to stimulating, incubating, and accelerating innovation, which is strongly driven by users' needs. At this level our work is focusing on three aspects: to capture, briefly, what we know so far about the process of encouraging schools to become more innovative; to describe the Discovery Space innovation model which is built upon these understandings; and to describe the practical programme of work which utilizes this model.

There is plenty of evidence pointing to the difficulty of incentivising and empowering teachers to engage in innovation, especially in tightly accountable systems based on performance targets. In education there is no shortage of energy and expertise, and certainly no lack of commitment or moral purpose amongst teachers. How could we support them, and give them the creative space and incentives they need to be innovative? What sort of interventions could both release professional imagination, whilst encouraging work that is disciplined and system relevant? How can the system learn from the resultant innovation and its process characteristics so that these can be taken to scale? How can busy, performance-driven teachers become aware of approaches and techniques which are emerging in other sectors - private and voluntary, as well as across public services more widely? It is enormously difficult in practice to be fully alert to developments and methods outside one's "zone of operation" (and sometimes even within it) which offer improvement potential. Some school leaders do manage to scan other horizons for ideas with transfer potential. How far can this be done on their behalf, to shortcut the investment of time, and also optimize the scope for adaptation?

5. Assisting behavioural change and professional development of teachers

Asking teachers to follow advanced ICT methods in their everyday teaching practice constitutes a major behavioural change and at the same a significant development opportunity for them. The task at hand is to manage this change in a uniform way, allowing teachers to realize the potential of the opportunity offered by the Discovery Space initiative, take ownership of their contribution and maximize the output for both the project and themselves. In a review paper [19], McKinsey management experts identify four key prerequisites for accelerating and establishing change:

A purpose to believe in: "I will change if I believe I should": The first, and most important, condition for change is identifying a purpose to believe in. In our case, we must persuade teachers of the importance of scientific literature in terms of social value, importance to their students and personal achievement through learning and teaching these important subjects. We must carefully craft a "change story" underlining the benefits that the project can offer to all the involved actors. Furthermore, we must cultivate a sense of community, making the teacher feel part of a cohesive multi-national team. This sense of belonging will prove very important for motivating teachers and asking them to take then next, possibly "painful" steps, of learning new skills.

Reinforcement systems: "I will change if I have something to win". From a pure Skinner behaviouristic point of view, changing is only possible if formal and informal conditioning mechanisms are in place. These mechanisms can reinforce the new behaviour, penalize the old one or, preferably do both. In our case, we can use informal reinforcement patterns in order to make teachers commit more to our project. A short list of such methods could include competitions, challenges, promoting the best teacher created content, offering summer schools as rewards, etc.

The skills required for change: "I will change if I have the right skills". A change is only possible if all the involved actors have the right set of skills. In the case of the Discovery Space project, the implementation team should make sure that the training program is designed in such a way that teachers acquire all the skills they will need, both technical and pedagogical.

Consistent role models: "I will change if other people change". A number of "change champions" will need to be established, acting as role models and change agents for the community of teachers. These very active and competent teachers will be a proof of concept for their colleagues that the change is indeed feasible, acceptable and beneficial for them. To achieve that we will have to identify the high flyers among the participating teachers and pay special attention into motivating them, supporting and encouraging them.

All four will specifically be addressed in each of the participating schools of the Discovery Space network. Additionally our team collaborate closely with teachers to develop a set of support services which help teachers to implement the necessary changes, to develop the diagnostics and intervention skills necessary to best plan and then diffuse innovation in their own contexts. An effective training approach provides the starting point for equipping teachers with the competences they need to act successfully as change agents, developing a language/terminology necessary to describe the dynamics of change processes, and making them able to recognize different forms of resistance and addressing it in their own context. At the same time it provides a common basis/experience for "connecting" teachers across schools, within and across national boundaries – engaging them in an ongoing exchange of experiences across school, regions and countries.

6. The Discovery Space Innovation Model

Taken together, the evidence set out above and the questions and issues it raises suggest some assumptions, which in turn have influenced the educational design of the Discovery Space approach.

The combination of a methodology derived from the available evidence base, with a mobilized group of empowered practitioners motivated by a compelling purpose, supported by dedicated innovation agencies in partnership with the key national bodies, will result in emergent Discovery Space implementation scenarios for the future science and mathematics classroom which will have system significance.

The right group to work with will be drawn from those practitioners who are already pushing at the boundaries of current practice in a chosen area. They will be well aware of practice deemed "best" – will perhaps have generated/adopted/adapted it. But they will be conscious too of its limits, and will have experienced the need to push on further, or in new directions. Skilled and self-confident, these are likely to be practitioners whose deep immersion, and success, in their work gives them the platform upon which to contemplate risk and to lead others. Visionary and energetic, their ideas spring from immersion in practice: not in theory or in ideology. They may well be alert to and interested in such fields, but the practical applications for their own "day jobs" are paramount. Indeed, it is likely that they have a wide field of vision. They will have a lively interest in the overall direction of the service in which they work, and be constantly scanning the environment for ways in which both to influence and exploit it.

Such an innovation programme holds great potential. If we want a powerful innovative culture in schools which is self-sustaining we have to empower system-aware practitioners, working ever more closely with the service users, to create it. And to avoid simply creating interesting but isolated pockets of experimentation, we have to design in collaborative ways of learning and enquiry between professionals – a "pull" rather than "push" approach.

Perhaps the most significant evidence to be considered in the search for how to foster practitioner-led innovation is that concerning the enablers and barriers. Innovators have some obvious needs including legitimation and support; and recognition and incentives (which need not be financial). They suggest also that the availability of experimental "space" can be critical – especially when it is closely tied to the involvement of end-users [20]. Barriers of course include the lack, or reverse, of the above conditions. But interestingly – from the perspective of the design of a support programme – also identified [21] is an over-reliance on high-performers as sources. This finding is difficult to interpret. At one level, such practitioners are invested in their already-successful approach; at another, they are well-placed to know the limits of current "best practice". To embark upon radical innovation requires, one could argue, confidence based on a secure reputation. Innovative initiative is likely to be regarded, (as Schopenhauer pointed out in relation to any "new truth') first with ridicule, then with violent opposition. Finally the outcome will be regarded as self-evident.

The underlying principles of the Discovery Space project approach are:

Creative community involvement: The consortium aims to create conditions for the development of teachers, new ideas, effective participation and new tools and applications to move the community into positive participation in a more equitable digital future. For this to happen the project will be led by interested stakeholders, on the basis of a strong process of creative educational community involvement. Indeed we should not try to force development into a pre-determined mold. The project team will not be repeating what has been done before. Thus creative community involvement plays a critical role in this project.

Design-based research: Design-based research methods respond to emergent features of the setting. Micro-analyses of teachers and learners interactions with activities based on this principle will enable redesign and refinement of the activities and ultimately refinement of the underlying interest-driven learning framework. Thus, emergent behaviours of learners in response to activities drive the development of both intervention and theory, which would have been unimaginable in the absence of real learners' choices. Finally, in a design-based research, practitioners and researchers work together to produce meaningful change in contexts of practice.

Such collaboration means that goals and design constraints are drawn from both the local context and the researcher's agenda, addressing a concern of many reform efforts. Engaging in such partnerships across multiple settings can uncover relationships between the numerous variables that come into play in learning contexts and help refine the key components of an intervention. In particular, these partnerships can help us distinguish between a "lethal mutation" [22] -a reinterpretation that no longer captures the pedagogical essence of the innovation- and a productive adaptation -a reinterpretation that preserves this essence, but tailors the activity to the needs and characteristics of particular learning environments-. Sustainable innovation requires understanding how and why an innovation works within a setting over time and across settings, and generating heuristics for those interested in enacting innovations in their own local contexts. In the early stages of the process, scenarios are used in order to plan the methodology and to characterize episodes or a sequence of activities (like in a story). These “stories” provide the context within which activities are carried out, so as to give us insights about the needs, difficulties and motivations that users have in particular contexts. Key elements for the Discovery Space scenarios are the users and their resistance to change, their goals, their needs, the sources of information accessed during the activities, and the information generated by the users themselves. Emergence of a community of inquiry does not happen by itself and does not emerge until considerable group dialogue takes place.

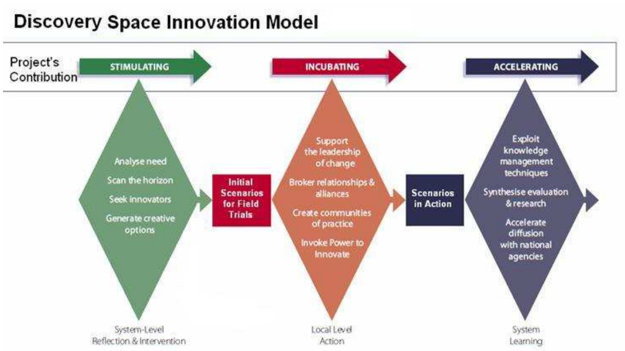

Figure 4. The Discovery Space Innovation Model will facilitate the introduction of innovation in a wide network of schools.

Teaching and learning techniques and activities that promote student-student interaction and that focus learning on problem solving and on applications to real-world experience, will enhance the development of such communities [23].
The design of the project’s approach for the introduction of the innovation is shown in Figure 4. Each phase is deliberately represented visually by a diamond: it seeks to capture the movement within each phase from an initial focus broadening to a wider set of generated possibilities, which subsequently become refocused.

The design process is at system level, and consists of reflection – followed by intervention – to clarify the specific practice to be the focus for innovation. The work of analysing the need and scanning the horizon may be of theoretical and policy interest, but the proposed approach seeks to involve potential innovators (including users) in these processes from the start, as a platform for action. Assembling the right practitioners – diverse, accomplished, motivated and already poised to drive forward if the right conditions obtain – is key if they are to be mobilised to embark on significant change. Generate Creative Options is focused on bringing such practitioners together with innovators and provocateurs from other sectors, and with users, to generate creative options for the project field trials. Activities might include focus groups, creative workshops, futures thinking, service design workshops, and the use of open space technology.

A very demanding task of the project’s implementation is expected to be the monitoring of the users’ activities. In several of our previous projects in the field of application of advanced learning systems, evaluation of the learning environments has been carried out and formative, summative, qualitative and quantitative approaches have been developed and improved. There is though an ongoing demand to improve this methodology in a reverse participation: We are used to ask for a participatory system design in the direction that users or other selected stakeholders participate in the design process, but we are not very much used to the perspective that the evaluation process itself is subject to an intensive participation process influenced by designers and users. This is the case in the Discovery Space approach. This hopefully will not only give new insights into learning processes but also into evaluation methods. Our work evolves through a systematic, multi-step assessment process involving the collection and interpretation of data. The project’s assessment places greater emphasis on the results of assessment procedures that sample an assortment of variables using diverse data-collection methods. Thus all aspects of the proposed approach are measured using multiple methods such as performances and portfolios, as well as interviews and questionnaires.

7. Conclusions – Next Steps

The described Innovation Model has been tested in practice in numerous school environments and it proves that facilitates
a shift in pedagogical practice among the staff, enabled by pervasive access to ICT throughout the school. The Discovery Space approach lays the groundwork with a

technical infrastructure supported by continuing efforts to introduce new ideas, support the development of technological fluency, methodologies to help harness creativity, and support to develop a pathway for the effective use of advanced technological applications in schools. The new technologies open the possibility of harnessing the enormous scientific and technological progress that has been made in the last five decades (in various fields of science and technology), by placing it at the service of one of the most important sectors of our societies.

Through the creative use of the new technologies and the learning processes they can generate with respect to local school problems, we can address the challenge of the "social appropriation of knowledge" seeking to empower teachers and students through this knowledge and to develop technologies that reflect the school needs. Additionally, the proposed educational approach can make a significant contribution to the development of self-esteem, an increased "sense of belonging", and an improved perception of one's own capacity to solve problems and contribute to the "construction of the surrounding community". These factors have been clearly related to the development of "social capital" and a greater degree of conviviality and peace. Footcloth the school component and the community dimension of the project place an emphasis on developing certain key values and attitudes that play an important role in this process, such as the capacity of team work and a spirit of collaboration as a way of developing learning networks and communities.

8. Acknowledgements

The Discovery Space initiative builds on the outcomes on numerous projects and initiatives in the field of technology supported science education. The author wishes to thank all the colleagues who have worked in these projects effectively introducing innovation in science classrooms in many European schools during the last 10 years. The Discovery Space approach has been significantly affected from their valuable contributions and experimentations.

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