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Sparking Innovation in STEM Education with Technology and Collaboration: A Case Study of the HP Catalyst Initiative

Kiira Kärkkäinen,

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SPARKING INNOVATION IN STEM EDUCATION WITH TECHNOLOGY AND COLLABORATION: A CASE STUDY OF THE HP CATALYST INITIATIVE

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How can technology-supported learning help to move beyond content delivery and truly enhance STEM education so that students develop a broad mix of skills? How can collaboration be encouraged and used to help develop, spread, accelerate and sustain innovation in education? The HP Catalyst Initiative – an education grant programme by the Hewlett Packard (HP) Sustainability and Social Innovation team – is used as a case study to answer these questions.

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ABSTRACT

This report highlights innovative technology-supported pedagogic models in science, technology, engineering and mathematics (STEM) education, explores what to expect from collaboration in a designed network, and, thereafter, sketches lessons for promoting educational innovation through collaboration.

How can technology-supported learning help to move beyond content delivery and truly enhance STEM education so that students develop a broad mix of skills? How can collaboration be encouraged and used to help develop, spread, accelerate and sustain innovation in education? The HP Catalyst Initiative – an education grant programme by the Hewlett Packard (HP) Sustainability and Social Innovation team – is used as a case study to answer these questions.

First, five technology-supported pedagogic models emerging from the Initiative are highlighted: gaming, virtual laboratories, international collaborative projects, real-time formative assessment and skills-based assessment. These models have the potential to improve students' learning outcomes, including development of higher-order thinking skills, and to expand the range of learning opportunities made available to students.

Second, the report explores the value of collaboration and support for innovation and outlines lessons for policy-makers and other stakeholders promoting educational innovation through collaboration. It shows that collaboration, especially international collaboration, can be an effective means to foster knowledge flows, new ideas and peer learning.

The results presented in the report are based on a mix of quantitative monitoring and qualitative case study methodology.

RÉSUMÉ

Le rapport met en lumière des modèles pédagogiques utilisant la technologie pour l'enseignement des science, de la technologie, de l'ingénierie et des mathématiques (STEM), explore ce que l'on peut attendre de la collaboration dans un réseau créé artificiellement, et, ensuite, en tire des leçons pour promouvoir l'innovation éducative à travers la collaboration.

Comment l'enseignement soutenu par la technologie peut-il aider à aller au-delà de la transmission du contenu des connaissances et améliorer l'enseignement des STEM afin que les étudiants développent une variété de compétences ? Comment la collaboration peut-elle être encouragée et utilisée pour aider à développer, à diffuser, à accélérer et à rendre durable l'innovation dans l'éducation ? La HP Catalyst

Initiative – un programme de subvention de l'équipe de Hewlett Packard (HP) pour la Durabilité et l'Innovation Sociale – est utilisée comme étude de cas pour répondre à ces questions.

Tout d'abord, cinq modèles pédagogiques utilisant la technologie émergeant des projets de l'initiative sont soulignés : l'utilisation des jeux, les laboratoires virtuels, les projets coopératifs internationaux, l'évaluation formative en temps réel, et les évaluations fondées sur les compétences. Ces modèles ont le potentiel d'améliorer les acquis d'apprentissage des élèves, y compris les compétences avancées de réflexion, et d'élargir les opportunités d'apprentissage proposées aux étudiants.

Ensuite, le rapport examine la valeur de la collaboration et de l'aide à l'innovation dans ce contexte pour en dégager les leçons pour les décideurs publics et autres parties intéressées cherchant à promouvoir l'innovation éducative à travers la collaboration. Le rapport montre que la collaboration, en particulier la collaboration internationale, peut être un moyen efficace d'induire la circulation des connaissances, et de développer de nouvelles idées et de l'apprentissage entre pairs.

Les résultats présentés s'appuient sur une méthode mixte incluant un suivi quantitatif et une approche d'étude de cas.

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EXECUTIVE SUMMARY

THE EDUCATORS' CORNER: TECHNOLOGY-SUPPORTED PEDAGOGIC MODELS

How can technology-supported learning help to move beyond content delivery and truly enhance science, technology, engineering and mathematics (STEM) education so that students develop a broad mix of skills? Could innovative teaching and learning approaches spark thinking and creativity, enhance student engagement, strengthen communication, and build collaboration? Would they make STEM teaching and learning more effective, more relevant, and more enjoyable?

Questions such as these – and a desire to investigate new pedagogic models – led the OECD Centre for Educational Research and Innovation (CERI) to use the HP Catalyst Initiative as a case study. The Catalyst Initiative is an education grant programme initiated and supported by the Hewlett Packard (HP) Sustainability and Social Innovation team. Many education systems increasingly recognise the importance of developing students' skills and understanding for tomorrow's innovation societies. Catalyst projects explore how innovative pedagogic models supported by technology might help develop student skills and understanding within STEM.

Five noteworthy technology-supported pedagogic models emerged from the research carried out by grantees within the Catalyst Initiative. The five broad models are associated with gaming, virtual laboratories, international collaborative projects, real-time formative assessment and skills-based assessment.

Educators should consider adopting these broad technology-supported pedagogic models to improve students' learning outcomes, including the development of higher-order thinking skills, and to expand the range of learning opportunities made available to students. The challenge of adopting these models is more to do with integration of new types of instruction, rather than overcoming technology barriers. Adoption also requires support from policy makers at a range of levels within education.

Technology-supported education can improve students' learning outcomes, including higher-order skills...

Students' higher-order thinking – above and beyond content learning – can be fostered by specific technology-supported pedagogic models. In Catalyst projects, models based on gaming, online laboratory experiments and real-time formative assessment increased test scores and conceptual understanding. In addition, in many cases they enhanced students' creativity, imagination and problem-solving skills**.**

For example, secondary education students using the Radioactivity iLab through its associated pedagogic resources at Northwestern University in the United States showed a 21% learning gain in science content, and 8% in science inquiry. Students measure radiation emissions as a function of how far they hold their cell phones from their ears. They design and run the experiments at home in the evenings at their own pace, produce lab reports, and then compare their results and experiences in the classroom with their teachers and fellow students.

The InkSurvey project at Colorado School of Mines in the United States also demonstrated increased conceptual understanding and increased creativity (measured by Torrance creativity tests). InkSurvey is a tool for real-time formative student assessment that enables student-instructor interaction in the style of clickers, but with much more detail as it can take a graphical form. While free play with interactive simulations increased student scores in chemical engineering by about 12% (or a full grade level), guided play with the help of InkSurvey-based real-time formative assessment increased scores by an additional 21% (or two full grade levels) – a finding that underscores the importance of instructor guidance.

In the United States, National University students considered that using Game Design Methodologies increased their creativity, collaboration and critical thinking skills, and their final grades increased by 5% when compared with results achieved through traditional instruction.

...and expand the range of learning opportunities made available to students

Technology also holds significant potential for expanding the range of learning opportunities available to students and for the formative assessment of a wide range of skills for innovation. The variety of learning opportunities and personalisation technology can offer may make STEM education more interesting and enjoyable for students.

Catalyst projects offer examples of technology-supported education that provide wider ranges of experimentation and learning-by-doing than are possible without technological support. Simulations provide one route to greater experimentation. Online laboratories (remote or virtual) using simulations can enable relatively low-cost flexible access to experiential learning. They can allow increased study time, and access to them can be offered in a way that is not tied to a specific timetable or location. For example, Kenya's Masinde Muliro University used science simulations to deliver chemistry tuition to rural students in locations that lacked power, Internet access and school infrastructure.

In addition, technology-supported simulations can allow the study of subject matter that would be almost impossible otherwise. Parents are likely to be unhappy if their children were to work with radioactive strontium-90 in a live laboratory. Remote or virtual laboratories offer the experience of studying and working with radioactivity safely.

Also no school can afford an unlimited supply of physical experimental resources. Online and remote laboratories, as well as other virtual environments, can be used to complement the on-site resources available and to enhance teachers' and students' teaching and learning opportunities.

Technology also increases possibilities for intercultural collaboration, overcoming geographical distance and formal classroom hours. For example, middle school students in Connecticut in the United States and Shandong Province in China worked together despite being a world apart, conducting real scientific research into water pollution. Similarly, undergraduates at Coventry University in the United Kingdom collaborated and planned teamwork in a virtual Built Environment project that required them to go through all the stages of a construction project with peers in Canada. These projects provided students with an opportunity to experience international collaboration, to gain insight into other cultures

and differences, and to be exposed to multicultural communication. This type of collaboration closely emulates the collaborative nature of today's international STEM professions.

Finally, technology facilitates real-time formative assessment and some forms of skills-based assessments that improve monitoring of student learning, and supports personalisation of teaching. Real-time formative assessment allows teachers to monitor student learning as it happens, and to immediately adjust their teaching to the needs of individual students. It may also enable the active participation of more students in the classroom discussion. The Eco-Virtual Environment of the City Academy Norwich (United Kingdom), a project based on virtual communication and real-time formative assessment, suggests that the pseudo anonymity of the virtual world provided a socially "safe" environment for students, particularly those who may view themselves as "low performers", to re-engage in discussions and collaboration with their peers. Technology-supported assessment enables monitoring of skills development and identification of the skills that should be acquired in a more comprehensive way than possible without technology. An example of technology-supported skills assessment is the Knowledge Broker web-service tool, devised by the French Ecole Centrale de Lyon, which seeks to enable the identification and evaluation of many skills by students themselves, by their peers and by their teachers.

Adoption of these models presents pedagogic rather than technological challenges...

New technology-enhanced educational models present not so much a technological challenge or cost challenge but a pedagogic challenge. The study shows that Catalyst projects typically require simple equipment (PCs, tablets, mobile phones) with Internet connections. Although the cost of these depends on the country or regional context (particularly where technology costs are measured against average or typical income levels), these are relatively low-cost resources often already familiar and available to teachers, especially in OECD countries. Many digital resources are also freely available to teachers: these include simulations in virtual environments (remote or online laboratories, games) and software for real-time formative assessment.

To adopt these new models requires teachers to revisit their pedagogy and this may amount to the greatest cost and challenge. The efficacy of the technology-supported models does not come from technology alone, but from the pedagogy that it supports. Without good pedagogic resources and a good understanding of how to use technology to foster deeper learning, these models may not yield the expected outcomes. Real-time formative assessment allows teachers to see in real time what students think and know, but they still have to use this information in their teaching to encourage students to reflect more deeply and to challenge their misconceptions. Experiential learning is most likely to provide expected improvements in conceptual understanding and scientific inquiry skills if teachers encourage students to repeat their experiments and provide students with a robust scaffolding to understand them.

...and receive adequate support from policy makers

The adoption of new technology-supported models by teachers is most likely to be sustained and effective when there is adequate support from policy makers.

Adequate technological infrastructure and the availability of a critical mass of teacher-friendly digital resources are necessary, though not necessarily sufficient conditions for large-scale adoption. While success is driven by pedagogy, technology-supported models generally require a certain level of equipment. A critical success factor in the innovation work of two-thirds of the Catalyst projects was the availability of adequate educational content and resources. Context counted a great deal for scaling up:

innovations must be responsive to local needs and educational structures. For example, the compatibility of Amrita University's online laboratories with the Indian National Curriculum and content review by relevant authorities were major factors supporting large-scale adoption.

In order to meet the pedagogic challenge mentioned above, adequate professional development for teachers is essential. A common barrier to adopting new teaching models and resources is lack of formal teacher training, peer learning and more. Half of the Catalyst projects reported that adequate professional development supported their success and, once beyond the stage of early adoption, this became even more important. As well as multiple professional development opportunities, the study shows teachers simply needed time to integrate new technology-enhanced educational models into their pedagogy. Two-thirds of the Catalyst projects cited lack of sufficient time for teachers as a challenge. This led to the creation of a platform of online professional learning for STEM teachers, the Catalyst Academy.

Finally, policy makers could help raise awareness of effective educational models among practitioners. An example of lack of awareness is that many educators appear to be unaware that online laboratories can be used with the same effectiveness as on-site physical laboratories, and many teachers overestimate the complications of technology-enhanced pedagogies.

THE FUNDERS' CORNER: COLLABORATION FOR SPARKING INNOVATION IN EDUCATION

How can policy makers and other educational stakeholders effectively support innovation in education to improve its quality and reach, and support a wider body of students? How can collaboration be encouraged and used to help develop, spread, accelerate and sustain innovation in education?

Questions such as these led the OECD Centre for Educational Research and Innovation (CERI) to use the Catalyst Initiative as a case study. The Catalyst Initiative is an education grant programme initiated and supported by the Hewlett Packard (HP) Sustainability and Social Innovation team. The Initiative has been developed in collaboration with leading education organisations from across the world with the aim of catalysing collaboration in order to accelerate and help scale innovation in science, technology, engineering and mathematics (STEM) education. Monitoring the HP Catalyst Initiative allowed the OECD to explore the role of collaboration in fostering innovation in education and draw general lessons for policy makers and other educational stakeholders wishing to encourage innovation in education. Establishing collaborative networks or clusters is a widely used strategy to stimulate innovation; it is, for example, used by the European Commission's framework programmes. In general, however, the outcomes of international collaborative grant programmes have not been widely researched.

The Catalyst Initiative was launched in 2010. From the beginning, the Initiative sought to stimulate international collaboration, and used this to accelerate and sustain technology-supported innovations in education. The OECD followed the Initiative's first two years of activity. During that time, the Initiative provided funding for 50 projects from 15 countries worldwide to develop innovations for STEM education – especially at secondary and higher levels. The Initiative encouraged international collaboration by grouping the Catalyst projects into six thematic consortia; it also encouraged the consortia members to develop collaborative relationships and to further develop, scale up, accelerate and sustain innovation. This design was intended to aid innovation. In addition to in-cash and in-kind resources, all projects benefited from training and continuous coaching support. Close monitoring and tracking of the Initiative generated a significant amount of data from which general lessons could be drawn. These lessons should be helpful to those seeking to encourage innovation in education through collaboration.

Ideas and innovation can flow from bringing together people from different backgrounds, regions and disciplines. Disciplined innovation seeks to provide some direction and shaping of innovation. For these reasons, policy makers and decision-makers wishing to promote innovation in education should leverage collaboration, especially international collaboration, as an effective means to foster knowledge flows, new ideas and peer learning. In addition to an adequate consortium structure, effective collaborative innovation initiatives benefit from support for face-to-face contacts and early mapping of objectives, methods and outputs, as well as early definition of monitoring and evaluation metrics.

Facilitate knowledge flows with collaboration and support

An explicit emphasis on collaboration can facilitate knowledge flows among grantees. Collaboration was most commonly selected as a top strength of the Catalyst Initiative and a common desire was for even more possibilities for collaboration. By late 2012, there were over 40 partnerships among Catalyst projects focused especially on testing and implementing innovative activities – often across national borders,

primarily within collaborative consortia. For example, within one consortium, Reach the World (United States) shared its online geography game GeoGames with Agastya Foundation (India) and introduced the Foundation's "mobile lab" and peer-to-peer educator models to its own students. The "mobile lab" model – now reaching more than 1.6 million students per year in India – has also been adopted by University of Fort Hare (South Africa). In addition, as a result of its participation in the Catalyst initiative, Reach the World is also collaborating with the Brazilian Center for Digital Inclusion to foster intercultural exchanges in the *favelas* of Rio de Janeiro.

Providing methodology, project management, collaboration and communication support to grantees can effectively enhance knowledge flows and foster quality innovations in education. Several Catalyst projects benefited from professional development in seeking future funding, and from training on using social media communication to raise programme visibility. Many were also helped through regular coaching to define their research questions, methodology and impact measurement. For example, the support provided under the Catalyst Initiative helped Kenyatta University in Kenya – working on technology integration through teacher professional development – to improve its project management and to write grant proposals for further funding.

Use collaboration to generate new ideas and peer learning

Collaboration can be a valuable tool to generate new ideas and peer learning. In addition to the support of Catalyst financing, Catalyst grantees reported new ideas for further work as a main benefit of the Initiative. Nearly two-thirds of the Catalyst projects reported that collaboration or exchanges within the Initiative resulted in new ideas beyond their original project design. For example, Catalyst face-to-face events led University of Washington (United States) and Masindo Muliro University of Science and Technology (Kenya) to plan the joint construction of a laboratory – supported by Catalyst incentive funds. While Masindo Muliro University lacked a facility to host teacher training and technology, University of Washington wished to provide its Built Environment students with the experience of remote design and construction. In India, Amrita University sparked student curiosity during a science camp with the help of Colorado School of Mines in the United States.

Many Catalyst projects benefited from intellectual, methodological or technological peer support through collaboration and exchanges. For example, the National Research Irkutsk State Technical University (Russia) received help from the China University of Geosciences with reviewing its platform and its educational model.

Provide opportunities for early and sufficient face-to-face contact

Effective promotion of collaborative innovation in education calls for early and sufficient face-to-face contacts. While collaboration requires time, even within a good collaborative architecture, early face-to-face contact can accelerate the exploration of possible partnerships, especially when the relationships are new and have to cross language and cultural boundaries. Participants need time to recognise opportunities and much of the collaborative work is associated with the development of human relationships, trust and understanding. Collaboration within the Catalyst Initiative intensified after face-to-face meetings, suggesting their importance for building engagement, interest and trust. For instance, collaboration among Catalyst projects took off after the first face-to-face international conference in New Delhi in March 2011. It peaked again after the Beijing conference in April 2012.

Boost collaboration with a well-defined or freely formulated consortium structure

A consortium structure can support collaborative innovation in education. Collaboration within a consortium structure may be generated by either defining consortia in detail or allowing their formulation through free association. Nearly two-thirds of the Catalyst projects reported benefiting from collaboration within their consortium. Consortia were particularly conducive to the formation of international partnerships, new ideas and peer capacity building. To encourage innovation, Catalyst consortia were defined by overarching guiding research questions, with the expectation that consortium members would themselves evolve their research agenda over time. For a few Catalyst projects, this approach proved to be challenging, especially for consortia consisting of project teams who were heterogeneous in terms of their areas of development, their objectives and organisation types.

The value of diverse teams may be enhanced by more precise definition of their objectives. One approach may be to provide beforehand a detailed definition of consortia objectives and expected outcomes to increase coherence and accelerate collaboration towards focused, specified goals. An alternative approach is to allow consortia to freely formulate their objectives, outputs and outcomes to foster especially open-ended innovation in education.

Use early detailed overview to facilitate and structure collaboration

A detailed and early overview of the substantive characteristics of both participants and projects can also accelerate collaborative innovation in education. Ideally, this mapping may start during the project selection process. The information gathered can then enable the linking of projects that work on similar topics or with similar approaches above and beyond consortium themes. One challenge to this mapping may be that in some organisations, the staff that identify the innovation themes, the organisation's objectives and its desired outcomes, may not ultimately be the same people that lead the projects once the grant has been received. A balance must be also found between directed collaboration and free, explorative collaboration. The Catalyst Initiative was intentionally launched with different project types, countries, education levels, STEM subjects, and areas of enquiry. A more detailed overview of existing projects in the very beginning of the Initiative may have helped to further accelerate collaboration synergies among projects and support the earlier development of a relevant reporting framework.

Define and communicate monitoring and evaluation metrics early on

Initiatives aiming to promote innovation in education need to define their monitoring and evaluation metrics in sufficient detail early on. Monitoring guides and encourages all participants towards the overall goals of the initiative, and evaluation provides feedback on its success. The Catalyst Initiative took monitoring seriously, running regular surveys and establishing a body of Executive Advisors. This information was subsequently used to continuously improve the Initiative towards desired goals.

Yet, these kinds of adaptations make the evaluation of educational innovation initiatives such as the Catalyst Initiative challenging. A few Catalyst project teams also struggled to adequately report their findings, even when they may have had positive outcomes. This is, in part, due to the early stage of innovation many projects were undertaking, and due to the need for more research capacity within project teams. To evaluate the impact of specific features of such initiatives, as well as their overall impact, an external comparison group, an internal comparison group or comparison over time could be used.

INTRODUCTION

Future economic growth and social progress rely on innovation. In addition to technical know-what and know-how, the core skills for innovation are critical thinking, creativity, problem-solving, global collaboration and communication (see for example OECD, 2010a; Toner, 2011). The challenge for education is to develop these different skills simultaneously (Avvisati and Vincent-Lancrin, forthcoming). This calls for innovation in education – for example new or improved educational technology tools, instructional methods, curricula, assessment approaches or ways for teachers to work together (OECD/Eurostat, 2005).

In 2010, Hewlett Packard's (HP) Sustainability and Social Innovation centre launched an international, collaborative grant programme promoting innovation in education: the HP Catalyst Initiative.[1] The Catalyst Initiative brought together 50 projects from 15 countries worldwide with the aim of developing innovative concepts and solutions for science, technology, engineering and mathematics (STEM) education, focusing on secondary and tertiary level students. The Initiative stresses the importance of interdisciplinary approaches to learning and the importance of skills such as creativity, collaboration, communication and cross-cultural awareness which together form a "STEM+" education. Technology in particular was seen as playing an important role in developing innovative concepts and solutions for future STEM+ education, in line with international research (OECD, 2010b). In order to develop, scale up, accelerate and sustain innovation in STEM+ education, the Catalyst Initiative placed a strong focus on collaboration in contrast to previous HP education grant schemes (Annex A). It encouraged collaboration, especially international collaboration, by grouping the Catalyst projects into six thematic consortia as well as through specific incentive funds. Each project benefited from over USD 158 000 in resources, both in kind, such as tablet computers, servers and printers, and in cash. The projects were also supported with training and continuous coaching support.

The Organisation for Economic Co-operation and Development (OECD) closely observed and monitored the Catalyst Initiative during its first two years as part of its Innovation Strategy for Education and Training. This strategy aims to better understand (1) what education and skills are conducive to innovation and (2) how to foster innovation in the education sector. The Catalyst Initiative offered a good case study to cast light on these two questions. First, the Initiative provided access to fresh ideas and promising STEM instruction models which aimed to foster the skills conducive to innovation including content knowledge, but also skills such as creativity, communication and collaboration. Second, the Catalyst Initiative emphasised international collaboration as a way to stimulate innovation and cross-fertilisation among its grantees – as do many other initiatives such as the framework programmes of the European Commission. Designing collaborative networks is a widely used strategy to stimulate innovation but there is little evidence about its effectiveness. One way to better understand what can be expected from such a programme is to monitor one that is big enough to offer many collaboration opportunities, and small enough to be observed thoroughly. The objective was thus to also get insights into the design, implementation and evaluation of collaborative grant initiatives and to draw some general conclusions for other stakeholders wishing to stimulate innovation in a similar manner.

This report highlights innovative technology-supported instruction models in STEM education, explores what to expect from collaboration in a designed network, and sketches lessons for policy makers

and other stakeholders promoting educational innovation through collaboration. The results presented in the report are based on a mix of quantitative monitoring and a qualitative case study methodology. The report is not an evaluation of the Catalyst Initiative, nor an OECD review, not only because the methodology was different, but also because the lessons learned are not primarily addressed to the designers of the Initiative but to the broader community of educators and education decision-makers.

More specifically, the report focuses on two broad questions:

- What technology-enhanced methods could be used to innovate and improve STEM education?
- How can collaborative grant programmes effectively develop, spread, accelerate and sustain innovation in education?

This report illustrates several promising technology-supported models in education and demonstrates the value of collaboration within a designed network as opposed to a spontaneous one. Taking into account the relevant research literature, the analysis builds on extensive quantitative and qualitative data collected on the Catalyst Initiative (Annex B).

After a brief overview of the Catalyst Initiative, this report highlights the promise of educational innovations such as gaming, online laboratories, technology-supported collaboration, real-time formative assessment and skills-based curriculum alignment. It briefly discusses the factors that policy makers and decision-makers need to take into account if they want to support the adoption of these models. The report then explores the value of collaboration and support in spreading, accelerating and sustaining innovation in education. Finally, it underlines lessons learned from strengths and challenges of the Catalyst Initiative for the benefit of other collaborative innovation initiatives in education.

The analysis in this report is partly based on three surveys of the Catalyst Initiative projects and consortium leaders. These were carried out in October of 2011 and 2012 to gather information about projects at the start, after one year, and after two years, reporting their findings, their activities within the Initiative and their opinions about it and how it was run (Annex B). Unless otherwise stated, all quotes and figures which are not referenced in the text come from these unpublished surveys. In some cases, we have used “HP Catalyst Consortia Leader Data 2011 and 2012” and “HP Catalyst Final and First Year Reports” to distinguish whether the information was reported by project leaders or by consortium leaders.

OVERVIEW OF THE HP CATALYST INITIATIVE

The Catalyst Initiative had three broad objectives: to spark technology-enabled innovations in STEM+ education, to foster collaboration and to build the capacity to scale up, accelerate and sustain innovation (Annex C).

First, the Catalyst Initiative aimed to demonstrate how "STEM+" education could look in the future, providing innovative examples of teaching and learning models to inform education policy. The Initiative worked on the basis that student-centred approaches are a key element for more effective STEM education and improved student outcomes. It saw increasing access to and use of technology as an important factor to provide wider access to innovative, better quality STEM education.

Second, collaboration both between and beyond the Catalyst members was meant to catalyse a network of organisations to increase their joint impact on innovation in STEM+ education worldwide. In particular, the collaborative and international nature of the Catalyst Initiative was expected to scale up successful innovations and disseminate them internationally.

Third, the Catalyst Initiative sought to enhance the capacity of individual projects to sustain their innovation work beyond the initial grant and scale it up. Specifically, the Initiative hoped that members would attract in total at least USD 1 million in external funding to further sustain their work on technology and STEM+ education. The evaluation metrics of the Initiative clearly reflected these aspects of collaboration and capacity building.

Design of the Catalyst Initiative

The Catalyst Initiative financed a wide range of STEM+ education work by selected higher and secondary education institutions as well as non-governmental organisations (NGOs). In total, 50 organisations were full members – 30 organisations joining in 2010 and another 20 since 2011. These individual projects were combined into six thematic consortia, each led by an additional "lead" organisation. In addition, 29 organisations participated in the Catalyst Initiative network as non-funded associate members, also within the consortia (Annex D). HP designed the six consortia and selected the leaders by invitation, then selected the full members through two competitive Requests for Proposals and with the support of a jury of experts. HP was looking for organisations that were thought-leading, credible and highly motivated, but the criteria for selecting the leaders were flexible with an emphasis on geographic balance. The eligibility criteria for full membership put a strong emphasis on the size of the applicant projects and their geographical spread. The additional guidelines highlighted a preference for projects that served disadvantaged students and were engaged in relevant networks through their previously funded work (Annex E).

Since 2010, HP Sustainability and Social Innovation committed more than USD 10 million to the Catalyst Initiative work, to be carried out over a two year period (Annex F). These resources were to a large extent directly allocated to the full members of the Initiative in in-kind and cash contributions, each receiving funding worth more than USD 158 000 in total. The in-kind part of the grant consisted mainly of technology such as tablet computers, servers and printers.

Catalyst members could also apply for competitive Innovation Fund and Leadership Fund cash awards – worth from USD 10 000 to USD 100 000 – aimed at accelerating collaboration and success of promising, scalable STEM+ education models. By the end of 2012, seven partnerships, consisting of 21 organisations in total, had been awarded an Innovation Fund grant and 10 members a Leadership Fund grant. These funds were used mainly to collaboratively disseminate technology-supported education to more (diverse) student populations. The Catalyst Initiative also provided non-financial support for collaboration including opportunities for face-to-face meetings, online communication infrastructure, training and coaching, regular monitoring, feedback and communication (Annex F). This support was provided especially by the International Society for Technology in Education (ISTE) and the New Media Consortium (NMC).

The structure of the Catalyst Initiative was designed to promote collaboration for innovation in STEM+ education at three different levels (Annex G). First, at the project level, the 50 Catalyst members carried out core research and development work on technology and STEM+ education. Second, at the consortium level, full and associate members were grouped together to enhance collaboration and innovation around specific themes such as informal learning, assessment or teacher professional development (Box 1 and Annex G). Third, the Catalyst Initiative overall provided a wider umbrella and support framework for collaboration and mutual learning within and beyond the Initiative (Annex F). For example, two face-to-face summits convening all projects – one in New Delhi, India, in 2011 and the other in Beijing, China, in 2012 – were planned from the start of the Initiative. The Initiative also set up an electronic platform to facilitate social networking, share information and materials and allow communication with others. Conference calls took place on a monthly basis between the consortia leaders and HP to support and exchange ideas on developments within the Initiative. HP also held monthly one-to-one discussions with each consortium leader, in addition to frequent e-mail contact.

A range of institutions who were leaders in their respective fields provided support for the Catalyst Initiative as Executive Advisors. The advisors included representatives from inter-governmental organisations such as the OECD. The Carnegie Corporation, C2k, the Consortium for School Networking, European Schoolnet, the Exploratorium, FutureLab, the Hewlett Foundation, ISTE, the National Science Resources Centre and NMC also provided expertise for the Initiative.

Box 1. The HP Catalyst consortia

Global Collaboratory

The *Global Collaboratory* consortium, created in 2010, promoted "transformation of STEM learning into an international project-based learning experience" by "bringing the world into the classroom and the classroom into the world". It explored themes of bridging cultures, languages and time zones as well as collaboration tools, models and barriers. The work built on possibilities provided by new technologies, particularly on grid computing network by HP and UNESCO Brain Gain Initiative. The consortium was led by Meraka Institute, South Africa, and comprised seven full members from Egypt, Kenya, the United Kingdom and the United States and five associate members.

Measuring Learning

The *Measuring Learning* consortium, created in 2010, concentrated on innovative approaches to assess STEM+ knowledge and skills, with a strong emphasis on real-time technology-based assessments. Specific attention was paid to measuring skills for thinking and creativity as well as social and behavioural skills. The consortium was led by Carnegie Mellon University in the United States, and comprised eight full members from seven countries, namely China, France, India, Mexico, Russia, South Africa and the United States. It included seven associate members.

Multi-Versity

The *Multi-Versity* consortium, created in 2010, focused on "understanding and disseminating effective practices" in online STEM education, in particular educational games, online laboratories, faculty development for online learning and models for online student interaction. The work built on the idea that, in the future, online education will become a central or even preferred way of learning especially in higher education, due to the increasing societal demand for more educated people. The consortium was led by Sloan Consortium, the United States, and comprised eight full members from Brazil, Canada, China and the United States as well as eight associate members.

New Learner

The *New Learner* consortium, created in 2010, investigated learning how to learn and the creation of personal life-long learning networks that – with the help of technology – build on formal, non-formal and informal resources and people. The new learners of the future were envisaged to "have their own network of learning resources […] for continuous learning of STEM+ disciplines", as opposed to current undervaluation of non-formal and informal learning. The consortium was led by Agastya International Foundation, India, and comprised 11 full members and four associate members, making it the largest within the Catalyst Initiative. Its membership covered Brazil, India, South Africa, the United Kingdom and the United States.

Pedagogy 3.0

The *Pedagogy 3.0* consortium, created in 2010, addressed innovations in teacher preparation to accommodate STEM+ learning in secondary schools, including the use of technology. The work built on the idea that "new and innovative approaches to teaching and learning aligned with new and developing technologies can be harnessed to increase and enhance learners' engagement in STEM+ subjects". The consortium was led by Futurelab in the United Kingdom, and comprised ten members and two associate members, making it the second largest within the Catalyst Initiative. Its membership covered seven countries – namely Australia, China, Germany, Kenya, Nigeria, the United Kingdom and the United States.

STEM-Preneur

STEM-Preneur is the most recent consortium, created in 2011 to address the possibilities of combining STEM and entrepreneurship education. At its heart lay an interdisciplinary learning experience for both technical and entrepreneurial minded students. The consortium was led by Tsinghua University School of Economics and Management in China, and comprised six full members and three associate members, making it the smallest within the Catalyst Initiative. The membership of the consortium covered Canada, France, India, Russia and the United States.

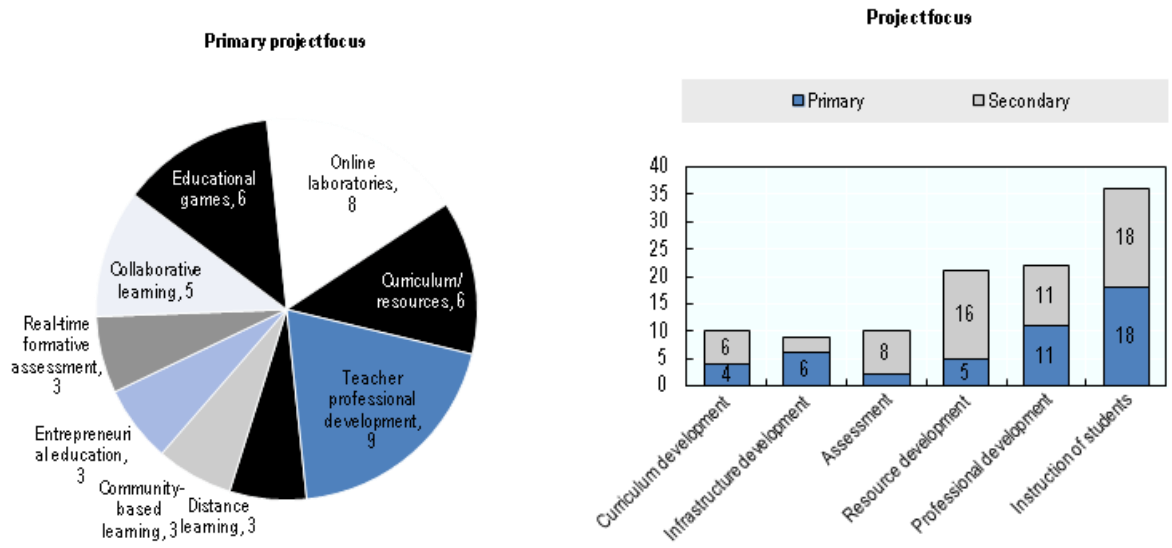
Source: HP Catalyst Request for Proposals 2010 and 2011; HP Catalyst Consortia Leader Data 2011 and 2012.

Diversity within the Catalyst Initiative

The substantive work of the Catalyst Initiative was very diverse in terms of pedagogic approaches geography, target groups and outcomes.

The Initiative provided students and schools with opportunities to try out various technology-enabled methods of STEM+ teaching and learning. The projects covered educational games, online laboratories, collaborative learning with the help of technology, real-time formative assessment, entrepreneurial education, community-based learning and distance learning (Chart 1). Some projects focused primarily on teacher professional development and others on curriculum or learning resources. Most Catalyst members covered instruction in some way as part of their activities, while nearly half addressed professional development and/or development of resources such as textbooks or other learning materials. A few projects included assessment and/or curriculum or infrastructure development in their work. Overall, the Catalyst members used technology in a variety of ways (Annex H). In line with the overall Catalyst objectives, the 50 projects sought to improve a variety of educational outcomes from student skills and STEM career attainment to teacher capacity and attitudes as well as to equitable education access (Annex I).

Figure 1. Activity focus by the HP Catalyst projects (46 projects)



Note: Classification of primary project focus is based on author's judgement. Some project focus data have been corrected taking into account narrative reporting.

Source: HP Catalyst Final and First Year Reports (2012).

The Catalyst projects operated in 16 countries worldwide, in diverse geographical and institutional contexts, although over one-third were confined to the United States (Annex D and J). China, India, Russia and South Africa each had three projects conducting activities exclusively on their territory. The other countries were Australia, Brazil, Canada, Egypt, France, Germany, Ghana, Kenya, Mexico, Nigeria and the United Kingdom, with some projects covering multiple countries. Projects covered urban, rural and suburban areas, with over half working in an urban or suburban setting. Most HP Catalyst members worked non-exclusively with public institutions and over one-third in a context where student admissions were not selective. Half of the projects worked at least in part with highly qualified teachers. While nearly one-third worked in a context where there were poor material resources, over one-third had rich material resources.

The Catalyst Initiative focused especially on higher and upper-secondary education students in various STEM disciplines (Annex D and J). A large majority of the projects targeted students in various STEM subjects, albeit not exclusively, with a balanced range of STEM subjects covered across the Initiative. Students in higher education were particularly targeted, with over two-thirds of the projects covering higher education, while nearly one-quarter covered upper-secondary education. Over one-third at least partly addressed students from disadvantaged backgrounds. In total, the projects aspired to target over 100 000 students; nearly 90% of which was meant to owe to scaling up projects by India's Amrita University and China's Beijing Normal University. The target groups were mainly either self-selected or the project activities addressed everyone in a particular context.

Overall, the substantive achievements of the Catalyst Initiative reflected its clear focus on developing and improving promising ideas in the field of technology-supported STEM+ education. While most projects carried out several activities simultaneously, such as validation, initial scaling up or large-scale expansion, over half conducted at least some improvement and/or development activities (Annex K). In line with this focus, the most common achievement for the Catalyst projects was new or improved models or tools, followed by improvements in student learning and behaviour (Annex L). Over half had developed a curriculum or parts of it, whereas one-third had developed pedagogical models and/or learning materials and one-third had developed some kind of measurement or assessment models. Over one-third of the Catalyst projects seemed to have increased technology use by students, and nearly one-quarter improved this use. Students' social and behavioural skills – such as interest or communication or collaboration skills – appeared to have been improved by nearly one-third of the projects. In terms of teacher outcomes, the most common achievement was increased and better use of technology by teachers; other types of teacher outcome were rare.

A FEW MODELS OF TECHNOLOGY-SUPPORTED STEM EDUCATION

What should "STEM+" education look like now and in the future? This section presents five innovative models of STEM teaching and learning explored as part of the Catalyst Initiative. These are educational gaming, online laboratories, collaboration through technology, real-time formative assessment and skills-based curriculum alignment. The emphasis is on practices that would be difficult to implement without technology and that can improve not just traditional learning outcomes, but also motivation, social, behavioural, thinking and creativity skills and their assessment.

Educational gaming

Educational gaming offers a promising model to enhance student learning in STEM education, not just improving content knowledge, but also motivation and thinking and creativity skills. Educators and policy makers should consider using it to enhance STEM learning outcomes and problem-solving skills and motivation. Designing games appears to lead to even deeper learning than just using them for educational purposes.

In educational gaming students interact with video games, simulations or virtual worlds based on imaginary or real worlds, also seen as highly interactive virtual environments (Raju, Ahmed and Anumba, 2011; Shaffer, forthcoming; Aldrich, 2009). Educational gaming also includes collaborative project-based learning experiences where students themselves become game designers and content producers (Prensky, 2008; Jaurez *et al.*, 2010; Raju, Ahmed and Anumba, 2011).

As a promising model for various disciplines and education levels, educational gaming may promote:

- *Learning by doing.* The interactive, reactive and often collaborative nature of educational gaming enable learning by doing of complex topics by allowing students to (repeatedly) make mistakes and learn from them. Real-life based gaming allows experimentation that would otherwise be too costly or dangerous. Gaming can be particularly useful when educating professionals who need the capacity to think and work simultaneously, while relying on tacit knowledge such as architects, engineers, chemists, physicists, doctors, nurses, or carpenters (Raju, Ahmed and Anumba, 2011; Lin, Son and Rojas, 2011; Shaffer, forthcoming).

- *Student learning.* Educational gaming which covers specific topics or subject areas and take place within a set of rules can increase students' achievements and subject-specific knowledge (Akinsola and Animasahun, 2007; Papastergiou, 2009; Yien *et al.* 2011; Bai *et al.*, 2012; Shaffer, forthcoming). Constructing educational games seems to increase deep learning more than just using existing games (Vos, Meijden and Denessen, 2011).

- *Student engagement and motivation.* Based on play and increasing challenges, educational gaming can foster student engagement and motivation in various subjects and education levels (Papastergiou, 2009; Annetta et al., 2009; Wastiau, Kearney and Van den Berghe, 2009; Lin, Son and Rojas, 2011; Yien *et al.*, 2011; Yang, 2012; Shaffer, forthcoming). Low-achieving students may find the educational gaming experience more engaging than high achieving students

(Grimley *et al.*, 2012). Students' motivation can increase more when they construct games themselves as opposed to just playing an existing game (Vos, Meijden and Denessen, 2011).

- *Students' thinking skills.* Games have the potential to help students find new ways around challenges, use knowledge in new ways and "think like a professional" (Shaffer, forthcoming). Educational gaming may also improve students' skills such as problem solving (Yang, 2012).

Two Catalyst projects illustrate the benefits of different kinds of educational gaming for various skills for innovation. The National University in the United States developed and validated a learning approach based on game design by higher education students. The City Academy Norwich in the United Kingdom created a virtual world simulation to teach middle school students the intertwined relationships between energy demand, finance and the environment.

Since 2010, the National University has been scaling up, validating and further developing its Game Design Methodologies (GDM) and related resources (Box 2). An interactive and collaborative project-based learning approach, the GDM provides students with "virtual apprenticeships" by making students the designers – as opposed to just users – of video games.

The aim is to engage students to acquire "detailed understanding of systems and relationships […] that form the rules and procedures, characters and challenges within the game". For further development and initial scaling-up within the Catalyst Initiative, National University has implemented the GDM in several of its courses and subsequently measured their impact on student learning. The idea is to make students design games with the help of tablet computers related to a specific theory or concept so that they better understand them: even though their games do not look or work like real games, they need to have some characteristics of them. For example, in a class on sustainability, the students designed games with dashboards and engines linking different measures relevant to the sustainability, covering situations such as energy management for a building, water management in the aeronautic industry, or waste from energy generation.

The GDM features have been generally well received by higher education students,[2] and initial results also suggest that it has benefits for various learning outcomes from grades to collaboration and engagement (see Box 2). For example, the use of GDM "increased final grades by as much as 5% vs. traditional scores" among 85 working adult students in the Economics course of National University and final grades of historical underperformers increased "> 10% vs. traditional underperformer scores".

For further dissemination of the GDM, National University has also created the web-based Game Design and Technology Learning Collaborative that allows course content and modules to be shared alongside example games created by students. By late 2012, the Collaborative had over 100 members online. In addition, video game speaker outreach and summer academies help National University to reach out to "precollege, at risk and marginalized students" with over 130 enrolments to the programmes and workshops with over 150 participants. The future objective is to expand to network to more partner organisations.

Box 2. Educational games within the Catalyst Initiative

Game Design Methodologies (GDM) of National University, the United States

The Game Design Methodologies (GDM) of National University in the United States, base instruction on interactive and collaborative project-based approach of video game design by students themselves. The GDM processes and principles were initially used in National University's "digital entertainment and interactive arts program, with the core objective of creating 'playcentric' video games" and later adapted to other courses such as engineering. In the GDM, students apply STEM content and principles in a systematic manner to build original video games using tablet computers. After the design phase, the games are played by student teams competing for the best gaming outcome relevant to the particular subject (Jaurez *et al.*, 2010). The games produced by students are meant to be reusable for higher education.

Further implementation and testing suggest the GDM made a positive impact on various student learning outcomes from achievement to collaboration, engagement and creativity. Experimental research on 85 working adult students, on site and online, on one month Economics courses at the National University demonstrated positive results. Playing games in the class benefited students in terms of understanding of "technical economics concepts directly related to the game", although it had "no effect on other subsequent subjects". The use of GDM "increased final grades by as much as 5% vs. traditional scores" and the impact was particularly positive for females with "> 5 % increase vs. female performance in Economics". Moreover, the final grades of historical underperformers – with below average grade point averages (GPAs) – increased "> 10% vs. traditional underperformer scores". The GDM students were found to be engaged and satisfied as well as to develop "writing, excel and presentation skills at a level" that they "otherwise would not achieve" The GDM students were assigned "to create original games to describe specific concepts in principles of microeconomics courses" in 2011 and 2012. Their performance was compared to that of students completing a traditional group paper assignment in 2010 and 2011. Both student groups had the same instructor (Altamirano and Jaurez, 2012). Additionally, self-reported student data suggest that the use of the GDM can be beneficial for learning, collaboration, engagement and motivation as well as for creativity and critical thinking. Students on Sustainability and Computer Ethics courses at the National University were asked to rate various features and impacts of the GDM on a scale of 1 to 5 (with 5 being the most favourable). The 25 Sustainability course students saw the GDM as valuable in increasing "depth of learning" (4.34), "'inter' and 'intra' team positive competition" (4.32), "engagement" (4.20) and "motivation" (4.16). The 18 students in the Computer Ethics course considered that the GDM increased "creativity and imagination" (4.44), "critical thinking skills" (4.33), "team collaboration and communication" (4.17), "engagement" (4.17), "motivation" (4.06) and "depth of learning" (4.00).

Eco-Virtual Environment (EVE) of City Academy Norwich, the United Kingdom

The Eco-Virtual Environment (EVE) project of the City Academy Norwich, in the United Kingdom, is a virtual world simulation focusing on environmental challenges. Students participate in the virtual world as part of a team and as creators of learning materials. In the EVE project "students are presented with an island that has growing energy demands". They are then required to "specialize and collaborate in order to design an energy network", while their "decisions will have real-time feedback in terms of power, finance and environment". The real-time feedback will then guide students' further decisions. With the teacher "in the driving seat", the simulation is meant to be organic and flexible. In terms of technology, the EVE project "looks and feels like a high-end computer game", using Google docs for the data feed and Opensim, making "the simulation usable on most computers without severe compromise to graphical quality".

Initial testing of the EVE project has suggested some positive impact on student communication and problem solving, although the impact on student learning is still to be further investigated. Limiting student communication only to the virtual world seems to generate better problem-solving results than the combination of virtual world and real-life discussions, especially for students who struggle in a traditional classroom context. One part of the 30-student test group "were given a dynamic environmental problem to solve [in small groups] by sitting around a table and discussing their actions". The other part, also in small groups, "were given the same problem but limited to 'in world' communication only"; they eventually "generated better solutions and produced more profit with less environmental damage". In the follow-up interviews, the students in the "in world" groups felt they owed these results to highly focused and measured communication. The students in the other groups reported "that their discussions often varied to non-learning based topics and arguments between team members were frequent". In terms of understanding, the quality of answers to questions such as "'If renewable sources of energy are so good why do we still have coal power stations?" were considered to be superior after time spent in the EVE.

The City Academy Norwich has focused on improving and validating its Eco-Virtual Environment (EVE) project (Box 2). Similar to a computer game, the EVE project is a virtual world simulation focusing on environmental challenges. Initiated in the context of a curriculum overhaul of the Academy, it aims to "engage students in an immersive virtual world to develop their collaborative skills, communication skills and understanding of global energy challenges". Instruction within the EVE project builds on collaborative learning and draws on skills in technology, science and mathematics to teach about environmental issues. Although its impact on student learning is still being tested, initial tests suggest a positive influence on communication and problem solving. Currently targeted at disadvantaged lower secondary students in England, the eventual ambition of the City Academy Norwich is to make the EVE project an international learning space – as it is "usable on most computers without severe compromise to graphical quality".

Online laboratories

Online laboratories, whether remote or virtual, are another promising innovation to enhance the teaching and learning of STEM at all levels of education. Virtual online laboratories allow students to simulate scientific experiments while remote ones allow students to use real laboratory equipment from a distance through the Internet (Jona *et al.*, 2011; Tasiopoulou and Schwarzenbacher, 2011).

Educators and policy makers should consider online laboratories as a promising way to increase access to a wide range of experimental learning. The use of online laboratories only requires access to the Internet and allows teachers and students to get access to more experimental equipment than a single school can generally provide. While remote laboratories can give students access to expensive equipment, virtual laboratories can allow them to vary the conditions for the experiments. Online laboratories are thus a good complement to – or substitute for – school science labs. The use of online laboratories can be at least as effective in terms of learning as the use of on-site physical equipment, and many resources are freely available on the web.

Policy makers could also devote some funding for and co-ordinate the development of online laboratory resources. As of 2013 there were 907 online remote high school laboratories listed worldwide on iLab Central (*www.ilabcentral.org*), a web gateway. Only a few could be publicly accessed via the platform though, offering remote access to equipment such as neutron spectrometers, radioactivity equipment, and equipment for measuring electronic circuits and devices. There were plans for public access to heat exchangers, inverted pendulums and shaking tables, but the small number of resources currently available limits wider adoption. Virtual online experiments are more numerous on open educational resource platforms.

As promising innovations especially for science instruction, online laboratories can (be expected to) offer the following potential benefits:

- *Lower-cost access.* Online laboratories may help bridge the digital divide by providing students with faster access to experimental learning at a relatively low cost (Burd, Seazzu and Conway, 2009; Flint and Stewart, 2010; Nedungadi and Raman, 2011; Jara *et al.*, 2011; Ku, Ahfock, and Yusaf, 2011). Simulations may be less expensive than experimental hardware, although "little empirical data exists on the actual costs of providing online laboratory access at scale" (Jona *et al.*, 2011).

- *Flexible access*. Online laboratories can enable flexible access to practical experiments, allowing increased study time that is not tied to a specific timetable or location. (Ku, Ahfock, and Yusaf, 2011; Almarshoud, 2011).

- *Student learning.* Online laboratories can help support student understanding and achievement at least as well as physical hands-on learning does (Yang and Heh, 2007; Pyatt and Sims, 2012; Chini *et al.*, 2012). Virtual manipulatives may be used in a blended format together with physicalmanipulatives of experimentation to further increase student understanding (Nedungadi and Raman, 2011; Olympiou and Zacharia, 2012).

Two Catalyst Initiative projects exemplify the power of online laboratories. Northwestern University in the United States has developed resources to use an online remote radioactivity laboratory to allow students to learn about specific concepts in biology, chemistry, mathematics and physics. Amrita University in India has developed online laboratories for upper-secondary physics and mathematics.

With support from the Catalyst Initiative and the United States National Science Foundation (NSF), Northwestern University has developed the iLab Network remote laboratory platform (Box 3). Focusing on scientific process, the iLab remote laboratories include student materials and assessments and allow students to access experiments from any place at any time provided they have access to the Internet. This gives them the opportunity to practice and experiment as much as needed. So far, the perceptions of both teachers and students about the iLab remote laboratories and their associated instructional features have been positive.[3]

An evaluation of the Radioactivity iLab and its associated pedagogy based on comparing pre- and post-test data for two groups suggests that it improves both the science understanding and the scientific inquiry skills of students (Box 3). For example, pre- and post-test data showed 21% learning gain in science content and 8% in scientific inquiry skills for secondary education students – with large and small effect sizes, respectively (Jona *et al.*, 2011).

Northwestern University has also sought to increase access to their iLabs and other STEM+ tools among disadvantaged lower and upper secondary students. Towards this end, it lends tablet computers and laptops that support the use of remote laboratories and other online resources to a number of classrooms each year, increasing iLab access for students in the Chicago area. As of early 2013, over 5 800 students have used the iLab Network, running over 8 000 experiments.

In India, Amrita University aims to scale up its Online Laboratories (OLabs) and related resources to 50 000 upper-secondary science students. By the end of 2012, 36 schools and over 9 000 students in the Indian state of Kerala had registered with its online laboratories, including both students in the registered schools and home-based online users. The project is intended to widen access to efficient and low-cost experiments as well as act a supportive learning resource for schools (Box 3).

Innovatively, the use of the OLabs by teachers is to be supported by a multilingual Collaborative Assessment Platform for Practical Skills (CAPPS) that includes a component to assess various skills of the students. Both teachers and students have a positive impression on the features and usefulness of the OLabs and CAPPS overall.[4] A significant milestone was achieved with an official circular from Chairman, Central Board of Secondary Education, recommending OLabs to over 13 500 schools across India.

Box 3. Online laboratories within the Catalyst Initiative

Radioactivity iLab of Northwestern University, theUnited States

The Radioactivity iLab is a remote online laboratory comprising a curriculum and related materials, developed by Northwestern University in the United States. The Radioactivity iLab enables students to "remotely control a Geiger counter to measure radiation being emitted from a sample of radioactive strontium-90" – with the actual laboratory equipment being located in the University of Queensland in Australia. Its objective is "to allow students to observe and experimentally derive the inverse square law", as they "use their data to mathematically describe the relationship between radiation intensity and distance". Students' skills in experimental design and data analysis are meant to be developed with the help of an online "lab journal" providing them with "instructions, readings, and meta-cognitive prompts". Students' reposes to the prompts, together with experimental data and graphs, are also saved "for students to submit to their teacher" at the end of the laboratory. The Radioactivity iLab experience is supported by a webcam view of the remote device and visualisations of its movements. It is asynchronous – meaning that students experiments are executed when the equipment "becomes available" – and does not require calibration prior an experiment (Jona *et al.*, 2011).

The iLab remote laboratories seem to bring about learning gains in science. A large-scale study of the Radioactivity iLab suggests "significant ($p < 0.0001$) pre/post learning gains in both science content (21% gain; 1.03 effect size) and scientific inquiry skills (8% gain; 0.37 effect size)". The study covered "20 teachers and 949 students, across five states in the United States" (Jona et al., 2011). Northwestern University's 2009 study of 594 high school students had already found that the "5-day iLabs curriculum produced a very large and significant increase in students' science content understanding and scientific inquiry skills". Students improved "15% points from pre- to post-test ($p < 0.0001$, effect size = 0.8)". It was "also found that providing students with the ability to conduct multiple experimental runs leads to better quality experiment designs and research question formulation" (Jona and Vondracek, 2013).

OLabs and Collaborative Assessment Platform for Practical Skills (CAPPS) of Amrita University, India

To help teachers to deploy online laboratories (OLabs), Amrita University has developed a multilingual Collaborative Assessment Platform for Practical Skills (CAPPS). OLabs include simulations based on mathematical models, interactive animations, remote equipment access and other rich-media learning material to enable students and teachers to conduct experiments in an interactive and collaborative manner. They can be used also as "a pre-lab learning tool to provide additional activities, to support teaching or learning of a concept and to evaluate the student". The cloud-based CAPPS is meant to allow a formal assessment not only of student understanding, but also practical skills related to science. These skills include both procedural skills (related to conducting experiments) and reporting skills (such as writing a lab report). For example, in an online environment, students' procedural skills could be assessed by asking them to select the right apparatus for an experiment or outline the sequence of steps. Assessment is based on a multiple choice format with immediate feedback and all the student's activities in an online environment can be tracked. These features can "help students focus and redirect their efforts to the appropriate task needed for mastery of a skill" (Nedungadi and Raman, 2011).

In addition to improving access, the OLabs and CAPPS appear to improve student performance in understanding science. The use of OLabs with physics students has shown significant pre/post-test gains ($t(26) = 6.58$, $p < .001$, $M = 3.33$ $SE = 0.51$). The collaborative research study shows OLabs appears effective based on the examination of the average group scores between mean pre and post tests (mean group performance gain in a paired t-test was $t(9) = 1.83$, single-tailed $p = 0.0001$). Total touch interaction with the tabletop and the average total time spent by a group were found to be the two main collaboration factors contributing to the performance gain – implying students working "jointly on the project, discussing together and taking turns interacting with the tabletop". Most students were positive, with 76% agreeing that OLabs improved their subject understanding and 70% that CAPPS provided them with greater control over their learning experience during the pilot testing in nine schools in Kerala in India. Of the 49 teacher workshop respondents, most agreed that OLabs would improve a student's understanding of a subject (87%) and enable students to learn faster (89%).

Initial pre- and post-tests as well as student and teacher reported data suggest that OLabs and CAPPS improve student science achievement and understanding (Box 3). For example, most students agreed that OLabs improved their subject understanding (76%) and CAPPS provided them with greater control over their learning experience (70%) during the pilot testing in nine schools in Kerala, India. With regard to 49 teacher workshop respondents, most agreed that OLabs will improve a student's understanding of a subject (87%) and enable students to learn faster (89%).

Collaboration through technology

Collaboration through technology can enhance students' interaction, engagement, learning and thinking skills, in addition to increasing flexibility and diversity in educational experience. Technology-supported collaboration can enhance students' awareness of global challenges and develop their understanding of other cultures.

Educators and policy makers should consider technology as a means to increase collaborative learning – also across long distances and between different cultures. Policy makers could facilitate this process by creating platforms for international collaboration among schools, classes, teachers and students. Collaboration can be supported by tools such as cloud computing, video-conferencing, or online platforms. New technologies allowing for real-time communication make international collaboration much easier than in the past.

For example, as a Catalyst project, students and teachers at Scofield Magnet Middle School in the United States and Shandong University Middle School in China collaborated on a water quality project with support from scientists and other experts. While the students in the United States examined the quality of their local groundwater, the Chinese students explored the Huangshui River Basin – one of the most polluted river systems in China. Students measured water quality, topography, drainage, flora and fauna, as well as the impact of urban development on water quality. With the help of technology, the project enabled students in both countries to compare their findings and reflect on the challenge of water quality internationally – and to increase their awareness of another culture.

In technology-enabled collaboration, students work together (in groups) and/or interact with each other to enhance their learning with the help of various technologies (Resta and Laferriere, 2007; Zhu, 2012) – often with facilitation from the teacher (Resta and Laferriere, 2007). When combined with other learning approaches, technology-enabled collaboration can form a part of project- or problem-based learning or supplement face-to-face learning (Resta and Laferriere, 2007). Technology-enabled collaboration models may include in-built assessment features taking into account also team performance and/or collaborative activity (Zhu, 2012).

As a promising model for STEM education and other disciplines at various education levels, collaboration through technology may improve:

- *Flexibility*. Technology enables students to collaborate and practice at "their own pace", beyond the formal classroom hours and without limitations of physical location (Resta and Laferriere, 2007; Zhu, 2012).
- *Cultural diversity*. Technology can significantly increase possibilities for intercultural interactions by broadening the scope of collaborations to distant locations, even across borders (Resta and Laferriere, 2007; Crawley *et al.*, 2008; Karpova, Correia, and Baran, 2009; Rogers, 2011; Rautenbach and Black-Hughes, 2012).
- *Student learning.* Technology-enabled collaboration may support student learning, in both individual and group outcomes (Resta and Laferriere, 2007; Thompson and Ku, 2010; Kelly,

Baxter and Anderson, 2010), although not necessarily more than face-to-face interaction (Tutty and Klein, 2008). There can also be cross-cultural differences (Zhu, 2012). In general, positive results of co-operative learning on student achievement have been shown to depend on group learning goals and individual accountability (Slavin, 2010).

- *Student interaction and engagement.* Technology-enabled collaboration can encourage student group work skills, interaction and engagement (Nevgi, Virtanen and Niemi, 2006; Resta and Laferriere, 2007; Nussbaum *et al.*, 2009; Kelly, Baxter, and Anderson, 2010). Yet, "active learning strategies' are not automatically adopted (Wang, 2010) and activity may differ across cultures (Zhu, Valcke and Schellens, 2009; Zhu, 2012). In general, co-operative learning has shown clearly beneficial results on affective student outcomes (Slavin, 2010).
- *Students' thinking skills.* Online collaboration may enhance higher order thinking even more than face-to-face collaboration through "more complex, and more cognitively challenging discussions" (Resta and Laferriere, 2007). This can also be the case for "questioning behaviours" and "project performance" (Tutty and Klein, 2008).

Three Catalyst projects highlight the possibilities of technology-enabled collaboration. Coventry University has focused on collaborative project-based learning between architecture undergraduates in the United Kingdom and Canada. The students use virtual collaboration for designing a building, including costs and construction plan. Renmin University's project combines in-class lectures and self-study with exploratory, project-based and collaborative online learning facilitated by an online platform. A third project from the National Research Irkutsk State Technical University uses technology for collaborative problem generation and solving.

In the United Kingdom, Coventry University has improved and validated a learning module based on a "project scenario for distanced collaboration between multi-disciplinary teams" (Box 4). The approach is meant to "develop people management skills through simulated learning environments/scenarios which resemble a real working practice of built environment professionals". Designed to foster students' communication and teamwork skills, the project asked students to work remotely with Canadian peers they did not initially know on a building design project. During the process, students learned to appreciate the importance of the quality of their communication. This approach has been tested with students from different backgrounds in Canada and the United Kingdom, including part-time and disadvantaged students. The module appears to be a success in terms of student satisfaction.[5] Virtual collaboration appears to improve planning for future work, but seems to have no significant impact on student performance. The participating students felt that the activity would have a positive impact on their employability. Trust building and "professional ethos of the students" emerge as "single greatest factor" of collaboration success.

In China, Renmin University has improved its online learning platform (Zask) and developed and implemented related blended learning courses (Box 4). These courses combined in-class lectures and self study with exploratory, project-based and collaborative online learning in order to enhance students' information technology (IT) knowledge and problem-solving skills. While students are expected to "take ownership of their own learning" and improve their teamwork skills, teachers have an important role as facilitators of learning. Students viewed Zask online discussions positively and showed interest in further participation in them, although they perceive limitations in the amount of online time available.[6] Although analysis of its effectiveness is still ongoing, the initial indications suggest a positive relationship between online collaboration and student performance. The initial Zask platform was gradually improved to combine "traditional communication methods and social network resources" with its YOU-niversity platform. Renmin University is continuing to further improve the system and plans to expand it to its Masters-level engineering education.

Box 4. Collaborative online learning in the Catalyst Initiative

International project-based learning at Coventry University, the United Kingdom

Coventry University in the United Kingdom has developed a module for virtual, distance and multidisciplinary collaboration between Built Environment students and explored its impact on various learning outcomes. The module focuses on a "building construction project in the initial stages of design development" and a role-playing scenario among students at different institutions. During the process, undergraduate students in Coventry University assumed the role of civil/structural engineers, while those in Ryerson University, Canada, took the role of architects. Student groups were formed based on their poster presentations, as they selected "the best group at the other institution aimed to complement their skills". The grading scheme combined "group and individual marks" with the peer-assessed group grade "derived from the team formation tasks, presentations undertaken and overall group report structure and cohesion". Although "no significant differences in individual and group marks between participating and non-participating students" were found, the results suggest that participating students may be better at planning teamwork. This refers to "developing a plan for monitoring, controlling and coordinating their work with the other team members" (N=249, t-test, p = 0.054). The analysis of interview data suggests that "professional ethos of the students" with subsequent building of trust was identified as the "single greatest factor" of collaboration success.

Collaborative online learning platform of Renmin University, China

Renmin University in China created blended courses applying its collaborative online learning platform to combine in-class lectures and self study with exploratory, project-based and collaborative learning. It developed three blended courses: Multimedia Technology and Application, Introduction to Program Design and Database Technology and Application. Students were able to solve problems, simulate using software and hold group discussions on the platform. The in-depth online collaborative exploration is preceded by lectures covering "basic points of the curriculum". Crucially, teachers also provide timely distant mentoring for students, "arrange online discussions based on the actual progress" and "help students solve problems along the conceptual framework". Drawing from the feedback and analysis, the supporting Zask platform was gradually improved from the initial 1.0 version to a web-technology supported YOU-niversity platform version 2.0. The improved platform combines "learning, sharing, collaboration, data collection and evaluation functions" and can be visited "through remotely accessible virtual environments". Initial indications suggest a positive relationship between online collaboration and student performance. In terms of collaboration, most "students have activated their accounts in the platform" and "taken part into online discussion and activities" (98%). Active collaboration in the platform seems to correlate with good performance in the Introduction to Database System course – for example seven of the top ten students in academic achievement were also in the top ten for collaborative activity. In addition, most students responding to a survey on its effectiveness perceived online collaborative learning to be supportive for their learning.[7]

MoPS collaborative problem-solving model of National Research Irkutsk State Technical University, Russia

The MoPS model being developed by National Research Irkutsk State Technical University in Russia focuses on interactive, collaborative problem-solving and peer assessment. It covers both problem generation and problem solving – the problems are meant to be customised for "preferred cognitive styles, temperament, physiological [traits] and age" of the participants. The model includes a peer-assessment component – expected also to act as a motivator for students – based on an automatically calculated rating of the problem generation and solving process. While "the initial rating for new participant is 0", correct answers increase the ratings of the student who disseminated the problem and the student solving the problem. In turn, "incorrect answers decrease the ratings". If either all or none of the answers are correct, the problem will be disregarded as too simple or too difficult – a "problem is considered being valid if a defined percentage of correct answers had been reached in the predefined interval of time". The role of the teacher is to "direct and coordinate cognitive activity of learners through active participation, such as generation of controversial tasks [or] setting of time limit for solving tasks". In terms of technology, MoPS works flexibly on mobile devices such as a personal computer or a smart phone. Problems can be generated and solved through diverse media such as photos, videos or audio files, while "the social network pattern provides a good distribution mechanism for a user-generated content" and stimulation of student activity. The model is based on Windows and Android operation systems and on peer-to-peer technology. It can be used with or without an Internet connection.

In Russia, the National Research Irkutsk State Technical University has started to develop the MoPS model for collaborative problem-solving and peer assessment (Box 4). The aim of MoPS is to "activate students' communication [skills] and creativity" through social contacts in a special social network. The model focuses both on problem generation and problem solving by students and teachers. Students generate new problems that they find worth solving, send them through their mobile devices to a randomly selected section of their peers, and then, if they are solved by enough students, to more extended communities. In this collaborative and interactive model, the peer-assessment component ensures the quality of problems generated with the help of in-built commenting and rating features. The role of the teacher is to co-ordinate activities and act as a quality "controller". Based on mobile technology, MoPS enables "learners to study at the convenient time and place using individual mobile devices" – such as personal computer or a smart phone – that allow for "reviewing old material as well as learning new" . In initial surveys, students and teachers have expressed excitement about MoPS. The first simulations have shown that a small group of students are able to "produce enough problems to activate work for all MoPS users".

Real-time formative assessment

Technology significantly facilitates the use of formative assessment – that is, frequent, interactive assessment of student progress and understanding (OECD, 2005). Clickers, tablet computers and other kinds of technology enable instantaneous interaction and feedback between teachers and students. In real-time formative assessment, software enables a variety of inputs to be used for student assessment including open format replies, student questions, pictures or mathematical formulas (Enriquez, 2010; Briggs and Keyek-Franssen, 2010; Kohl *et al.*, 2011; Gardner, Kowalski and Kowalski, 2012; Universidad de las Américas Puebla, forthcoming). Some of the software is freely available. Real-time formative assessment can be combined with various instructional models.

Educators and policy makers should consider the use of real-time formative assessment as a way to enable more personalised learning. The immediate feedback it provides allows teachers to personalise their instruction to the needs of individual students or to specific groups of students. Real-time formative assessment can also ease the participation of every student in classroom discussions – something that does not generally happen in group instructions, for example because of time constraints or shyness.

As a promising educational innovation, real-time formative assessment could enhance:

- *Targeted instruction.* Real-time formative assessment allows teachers to monitor student learning as it happens and better adjust their teaching to the needs of individual students (Enriquez, 2010; Briggs and Keyek-Franssen, 2010; Kohl *et al.*, 2011; Gardner, Kowalski and Kowalski, 2012).

- *Student learning*. Real-time formative assessment can increase student achievement by promoting students' reflection about the needs of and engagement in their own learning (Enriquez, 2010; Briggs and Keyek-Franssen, 2010; Gardner, Kowalski and Kowalski, 2012; Wu *et al.*, 2012).

- *Problem solving and creativity.* Real-time formative assessment provides avenues for assessing different types of activities and variety of student skills such as problem solving or creativity – potentially enhancing the acquisition of these skills (Looney, 2009; Enriquez, 2010; Kohl *et al.*, 2011; Looney, 2011a; Wu *et al.*, 2012; Gok, 2012).

One Catalyst project exemplifies different ways of using real-time formative assessment in STEM education. The Colorado School of Mines project allows science and engineering higher education students

to give open format input such as graphs or drawings to ensure a rich and frequent student engagement in the learning process.

In the United States, the Colorado School of Mines has explored the effective use of "mobile technology to facilitate real-time formative assessment" and support student creativity (Box 5). The real-time interaction aims to engage "students in their learning", while "the instantaneous feedback to the instructor informs subsequent instruction". Towards this end, Colorado School of Mines is improving and validating its InkSurvey software – "a free, web-based tool that allows students [with the help of tablet computers] to use digital ink to respond to open-format questions posed by the instructor". As part of the exploration effort, a creativity course in physics facilitated by InkSurvey has been "developed and delivered to a variety of student populations" – an effort leading also to an "entirely new direction of investigation" of developing a tool for creativity assessment in physics. The project has been scaled up to give high school and community college teachers access to InkSurvey in their classrooms. It has been used in undergraduate and graduate-level classes at the Colorado School of Mines and Universidad de las Américas Puebla, Mexico.

Coupling real-time formative assessment using InkSurvey with interactive computer simulations seems to increase students' conceptual understanding. Initial trials on the creativity course in physics suggest a positive impact on student creativity (Box 5). For example, while free play with interactive simulations increased student scores in chemical engineering by "~12%, or a full grade level", guided play with the help of *InkSurvey*-based real-time formative assessment increased scores "an additional ~21%, or two more full grade levels" (Gardner, Kowalski and Kowalski, 2012).

Box 5. Real-time formative assessment in the Catalyst Initiative

InkSurvey of Colorado School of Mines the United States

InkSurvey of Colorado School of Mines in, the United States is a tool for real-time formative student assessment that "enables student-instructor interaction in the style of clickers, but with much more detail". Students use tablet computers or other pen-enabled mobile devices to "write answers to open format questions (not multiple choice), ask their own questions, provide their level of confidence in their own answer," or digitally submit text answers as well. The instructor can "instantly see and scroll through all students' answers to get a feel for what was understood and what was misunderstood". The "digital ink" enables the answers to take a format of "equations, graphs, drawings, words [or] numbers". The refined and improved version of InkSurvey helps processing of information by allowing the "instructor to sort submitted responses into categories, either as they are received or later". It includes "full functionality on iPads and on pen-enabled Android devices" in addition to tablet computers. The new features – "such as screen size, scrolling capacity, eraser function, and student identification" – make InkSurvey also more user-friendly.

Real-time formative assessment combined with other instructional methods can help enhance students' learning gains. Colorado School of Mines coupled InkSurvey-based real-time formative assessment with interactive computer simulations – another method aimed to "get students actively engaged in their own learning". After pre-tests (PRE), students were "asked to [freely] play with the [interactive simulations] with the goal of understanding as much as they could about the behaviour of the systems". This free play was followed by another assessment of understanding (after free play, or AFP). Students were finally "allowed to explore the same [interactive simulations] again [in class] while responding to a series of scaffolded questions" through InkSurvey. Guided by these questions, students discussed with each other and could use InkSurvey to ask anonymous questions to the instructor. As a test afterwards, students "were given the same broad questions after the guided play, and these were assessed, resulting in the [after guided play] AGP scores". For all six chemical engineering topics assessed "the AGP averages were statistically higher than the AFP averages". Regarding three topics, "the AFP averages were statistically greater than the PRE averages, indicating that free play with the simulations did improve the students' understanding of the topics". Overall, "the average increase in score was ~12%, or a full grade level, after the free play, and an additional ~21%, or two more full grade levels, after the guided play". Moreover, students were found to be engaged in tasks by independent classroom observations (Gardner, Kowalski and Kowalski, 2012).

Initial trials suggest that explicit instruction in creativity with the help of InkSurvey can improve student creativity, although it is "not completely clear that the gains come from instruction" instead of the testing experience itself. Colorado School of Mines has developed an elective course aimed at developing "creativity and innovation in physics majors" with the help of InkSurvey and tablet computers that allow students to be mobile around the classroom. The Developing Creativity and Innovation in Physics course draws on "corporate and industrial approaches to creativity" such as information gathering, idea generation, words association and analogical reasoning. The course explicitly covers "the topic of measuring creativity" and students have the opportunity to hear the views of an industry guest speaker. The pre/post-impact of the course on student creativity was tested with six senior physics majors in 2010 and ten second-year undergraduates in modern physics in 2011 by using Torrance Tests of Creative Thinking – verbal format for the undergraduate and figural format for the graduate students. The results suggest "that student performance increases significantly [$p \sim 0.02$-0.03] from pre to post in every subcategory of the verbal test". Although pre to post "differences for the figural test [...] are less pronounced", they are statistically significant (~ 0.04) for overall creativity as well as for originality in particular. The Torrance test is discipline independent and includes various scoring dimensions for fluency, originality, elaboration and flexibility. The trials with the Developing Creativity and Innovation in Physics course have fed into efforts to develop "a pilot version of a physics-specific creativity assessment", adapting parts of the Torrance test and drawing on student and faculty discussion at Colorado School of Mines (Kohl *et al.*, 2011).

Skills-based curriculum alignment with technology

Using technology for skills-based curriculum alignment can promote more accurate assessment of the variety of skills included in STEM+ curricula and standards. While it is becoming increasingly common to develop these kinds of skills-based curricula, their eventual impact on actual teaching and learning depend also on the availability of adequately aligned support systems (Ananiadou and Claro, 2009; Looney, 2011b; Kärkkäinen, 2012). This is particularly true for student assessments, but also for learning materials, teacher guides and teacher professional development (Ananiadou and Claro, 2009; Kärkkäinen, 2012). To

truly promote certain skills, one needs to be able to adequately measure those skills to give teachers an incentive to teach students towards that direction (Looney, 2009). In contrast, assessments that are poorly aligned with standards and curriculum make it "impossible to draw valid conclusions about the success of student learning" (Looney, 2011b). Although "no system can achieve perfect alignment" (Looney, 2011b), technology can become a great support in developing adequate measures for approaching this goal.

As a promising innovation for advancing STEM+ skills, technology can improve adequate curriculum alignment through:

- *Adequate assessment.* Technology can help measure complex skills such as reasoning or problem-solving through measures such as essays, blogs or virtual learning environments (Looney, 2009; Looney, 2011b; Ramirez-Corona *et al*., 2013).

The Ecole Centrale de Lyon in France has targeted itsCatalyst Initiative involvement since 2010 to scaling up its national skills-based learning framework – aiming to transform higher education engineering teaching from knowledge-centred to skills-based learning (Box 6). Towards this end, it was the "leader of a national certification program called 'IT-Skills for engineers' developed with the [French] Ministry of the Higher Education" and ten other institutional partners. The programme covers skills such as IT skills, research and communication and emphasises instructional approaches such as project- or problem-based learning. Its resources for implementation include skills referential, an implementation guide and a portfolio tool to evaluate the quality of the programme and the amount of skills-based activities.

The Ecole Centrale de Lyon has scaled up its skills-based learning and "spread the skills-based approach in the whole curriculum". In France, the ongoing scaling-up process of the IT-Skills for engineers programme involves a community of "55 universities and engineering schools". The *Commission des Titres d'Ingénieur* – "an independent body in charge of evaluation and accreditation of engineering curricula and institutions" – has included the "IT skills approach in its new guidelines" reaching "more than 200 engineering schools". A common web-based tool called COPEAR facilitates 35 French universities and schools to share activities and evaluation processes. Ecole Centrale de Lyon has been asked "to collaborate in a national group to rethink the referential to spread IT skills for not only engineers, but lawyers, the health sector and environmental sector". Universities outside of France have also shown an interest in the programme.

In Mexico, Universidad de las Américas Puebla has designed support systems for developing the 21st century skills needed by engineering students (Box 6). The work takes place in the framework of a recent reform of the undergraduate curricula for chemical, food and environmental engineering that centres around nine department-wide "pillar" courses. By late 2012, the support system development had resulted in standards, learning environments and professional development opportunities for instructors of the pillar courses as well as formative and summative assessments appropriate for these 21st century skills. The pillar courses aim to "improve student understanding of the engineering method, ability to solve practical problems and complete real-world projects" by emphasising problem-solving learning environments. The objective is also to enhance interaction, feedback and evaluation for and between students and teachers. Initial indications suggest that courses developed can improve students' metacognitive awareness, which is seen as beneficial for problem-solving, while technology-enhanced formative assessment seems to support student motivation and reflection.

Box 6. Skills-based curriculum alignment with technology in the Catalyst Initiative

A skills-based learning framework of Ecole Centrale de Lyon, France

The Ecole Centrale de Lyon's skills-based learning framework aims to transform the teaching of higher education engineering from concentrating just on technical knowledge to learning also skills such as IT, research and communication. The resources used to support implementation of the programme include a skills referential, a skills implementation guide and a tool "dedicated to collect and share ways to evaluate [a variety of] skills". The guide describes each competence, provides training and evaluation guidelines for each competence domain, and lists websites and documents for further reference. With emphasis on project- and problem-based learning, the training and evaluation guidelines suggest a variety of activities that can take place in classrooms or during internships and be done individually or collectively. For example, students in Ecole Centrale de Lyon are required to conduct a year-long team project with dedicated time of four hours per week.

Towards alignment, teachers from the Ecole Centrale de Lyon have developed a tool "dedicated to collect and share ways to evaluate [a variety of] skills" based on a knowledge management approach. So called units of knowledge are gathered, formalised, improved and shared under the secured web-service. In this framework, knowledge balance specifies the competences, knowledge blog defines "the knowledge content of a given competence" and knowledge base automates "the reasoning process of a given competence". When tested with student teams designing ecological race cars, knowledge balance identified 238 competences for this specific task. The transmission of knowledge between teams was facilitated by writing Knowledge Blogs that are "enhanced every year by new teams of students". While different measures can be combined "to validate one specific skill", the skills measurement is seen as dependent on factors – the type of skill (individual, collective, know-how, behavioural), the evaluator (teachers, peers, one self, professionals), the activity (project work, problem-based activity, internship), the place (classroom, extra-curricular, workplace) and the type of evidence (tests, direct observation, individual/ collective portfolio). In skills-based framework, for example students' behavioural skills are assessed with a 360° evaluation – including self- and peer-assessments – at the end of the project. In this case, most "students (more than 70%) generally underestimate their skills acquisition compared to the team opinion".

Support systems for 21st century skills in Universidad de las Américas Puebla, Mexico

The Universidad de las Américas Puebla has developed support systems for developing the 21st century skills needed by engineering students. These tools include standards, professional development opportunities, learning environments, instruction activities and assessments. The systems particularly target nine "pillar" courses for undergraduate chemical, food and environmental engineering students. They focus on increasing active student participation as well as peer- and team-interactions, and improve feedback processes and formative assessments. For example "several problem-solving learning environments (PSLEs) for the junior course entitled Kinetics and Homogeneous Reactor Design" were developed. The course focused on meta-cognition in order to develop engineers' ability to solve workplace problems that may differ from those solved in classrooms. Towards this end, "the instructor created a supportive social environment in the course and inserted a series of question prompts during PSLEs, as a form of coaching where the problem to be solved was represented as a case". The cases served as "instructional supports" and included "worked examples, case studies, structural analogues, prior experiences, alternative perspectives, and simulations". Pre and post assessments suggests "a significant ($p<0.05$) increase in student metacognitive awareness" as measured by a 52-item Metacognitive Awareness Inventory (MAI). The result was "also noticed by means of the embedded MAI prompts while solving different kinds of problems [...] throughout the course" (Ramirez-Corona *et al.*, 2013; see also Ramirez Apud *et al.*, 2012).

Tablet computers and associated technologies were used for assessments to "improve chemical engineering teaching and learning by creating high-quality learning environments that promote an interactive classroom while integrating formative assessments into classroom practices". With tablet computers for every student, the associated technologies OneNote, InkSurvey, and Classroom Presenter were used in two junior and two senior chemical-food engineering courses. The objective was to "gauge student learning in real time, provide immediate feedback, and make real-time pedagogical adjustments as needed, especially in the redesigned problem-solving learning environments". Semi-structured interviews with three students suggest that the use of tablet computer technologies "increased their motivation to participate in class and enhanced their scores in graded work-products". Also activity in classrooms and of learning experiences seemed to improve and trigger student reflection together with real-time feedback (Palou *et al*., 2012). Similar results were obtained also with structured interviews of 12 graduate students in advanced food chemistry (Gutierrez-Cuba, López-Malo and Palou, 2012).

Considerations for adopting new teaching and learning models

Different technology-supported innovations in STEM education still tend to be marginal in most schools. Bringing them into the mainstream instructional practice depends on the availability of the technical resources and support they rely on. They also need to be compatible with local context and educational structures such as the relevant curriculum. It is also important to provide sufficient professional development, administrative and political support as well as time for implementation (Snyder, Bolin and Zumwalt, 1992; Darling-Hammond, 1998; Dede, 2006; Fullan, 2007; OECD, 2009; Kärkkäinen, 2012).

Educators, policy makers and other stakeholders should consider developing strategies to facilitate the adoption of technology-enhanced innovations in STEM educations, addressing the following issues:

- *Awareness of new models.* One common challenge faced by technology-enhanced educational models lies in the lack of awareness of their existence. For example, many teachers or decision makers do not know that online laboratories can be used with the same effectiveness as physical laboratories on site.

- *Over-estimation of the complication*. Technology-enhanced teaching models may have connotations of difficulty or frivolity that deter some teachers. However, virtual collaboration does not necessarily require very sophisticated technology. Similarly, the use of some online laboratories may only require access to the Internet. The perception that technology-enhanced learning is difficult may relate to teachers' lack of interest in technology or lack of competence in the models that they support – two problems that can to some extent be addressed by professional development.

- *Equipment and funds*. One hindrance to the use of technology-enhanced learning lies in the lack of equipment that still characterises many schools in OECD countries. For example in the European Union, in 2012, on average only 37% of 4th grade students and 24% of 8th grade students studied in a highly digitally equipped school, characterised by relatively high equipment levels, fast broadband and relatively high connectedness (European Schoolnet, 2013). The lack of operational funds for schools to carry out collaborative or innovative projects or to purchase digital resources and devices may also hinder the widespread adoption of these new practices.

- *Relevant digital resources*. Another challenge for the adoption of technology-enhanced education lies in the availability of enough relevant resources (Chart 2). For example, in spite of their growing number, it would take far more online remote laboratory experiments to see them become part of mainstream education. Moreover, many of the resources may not be seen as relevant to other contexts than those in which they were developed. Existing resources could be adapted to the local curriculum, or tagged in ways that make them easy to find (Chart 3 and Annex M).

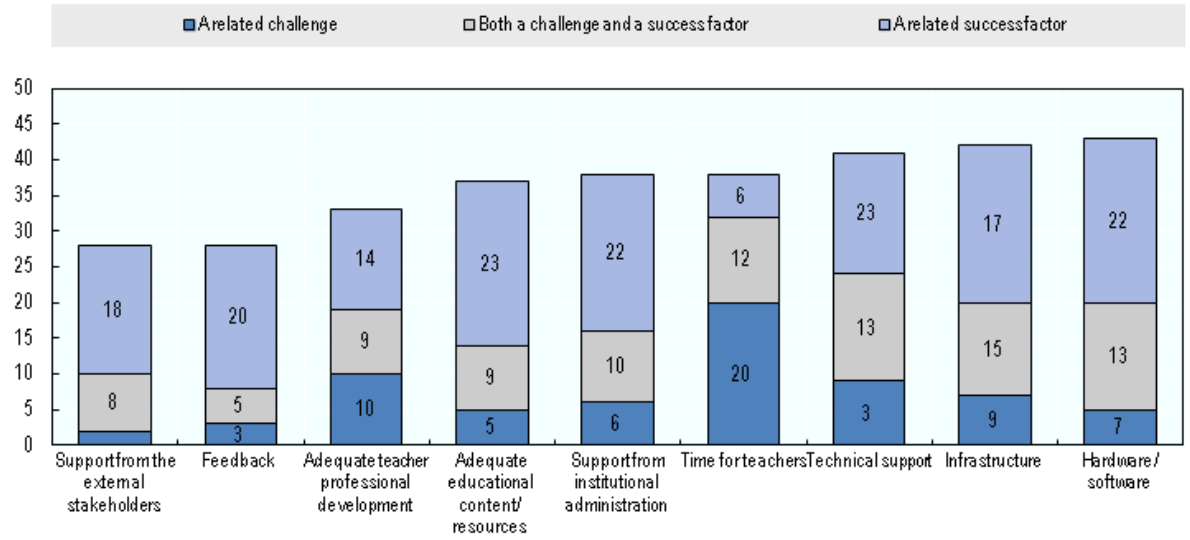
- *Compatibility with educational structures*. In some cases, the innovative nature of the educational models may make them difficult to adopt within existing educational structures. A success factor for the work of two-thirds of the Catalyst projects was the availability of adequate educational content and resources. For example, the implementation of a skills-based curriculum by the Ecole Centrale de Lyon was initially challenged by existing conceptions about curricula in the sector, and it is thanks to the support of other local engineering schools interested in their IT skills referential that the model has gained ground. Similarly, the compatibility of the online laboratories of Amrita University with the Indian National Curriculum and the review of its contents by relevant authorities are a major factor supporting their large-scale adoption (Chart 3 and Annex M).

- *Professional development*. One common barrier to the adoption of new teaching models or resources lies in the lack of professional development, including both formal teacher training and peer learning. Even at the development stage, providing professional development is a key factor for success for the successful implementation of a teaching model. Half of the Catalyst members reported that adequate teacher professional development supported the success of their project (Chart 2). As these models spread beyond the early adopters, it becomes even more important that they are accompanied by enough resources for teachers to get formal or informal training. Opportunities for timely peer learning within schools, when and as needed, tend to be the most effective (Hennessy and London, 2013). As a new development of the Catalyst Initiative, HP has launched a Catalyst Academy in 2013 to provide online learning experiences for teachers.

- *Time to try new approaches*. Sheer lack of time of teachers either to search for new resources and new information or to take formal and informal training can be a major obstacle to new teaching models. Policy makers and decision-makers should consider the possibility of giving at least some teachers some release time to help their colleagues, organise existing resources for the local needs, and investigate the possibilities offered by new technologies. Lack of time for teachers has been a challenge for the work of two-thirds of the Catalyst projects – by far the most common of all challenges (Chart 2 and Annex M). For example, in Coventry University, teachers often invested their own free time to support the work on project-based learning with virtual collaboration.

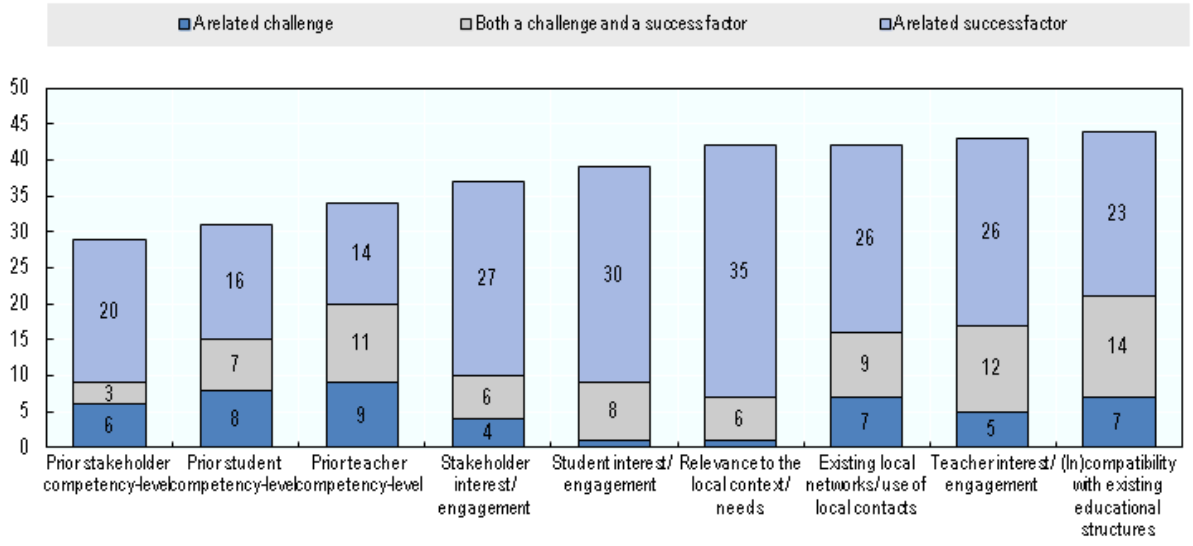
- *Administrative and political support*. Support from colleagues, be they other teachers, school leaders, administrative or technical staff, or external stakeholders is also important for the adoption of new technology-based pedagogies. This has proved to be true for many Catalyst projects in their development or validation phase (Chart 2 and 3 and Annex M).

Figure 2. Resource considerations for achieving outcomes of Catalyst projects (46 projects)



Source: HP Catalyst Final and First Year Reports (2012).

Figure 3. Contextual considerations for achieving outcomes of Catalyst projects (46 of projects)



Source: HP Catalyst Final and First Year Reports (2012).

COLLABORATION OUTCOMES IN A DESIGNED INNOVATION NETWORK

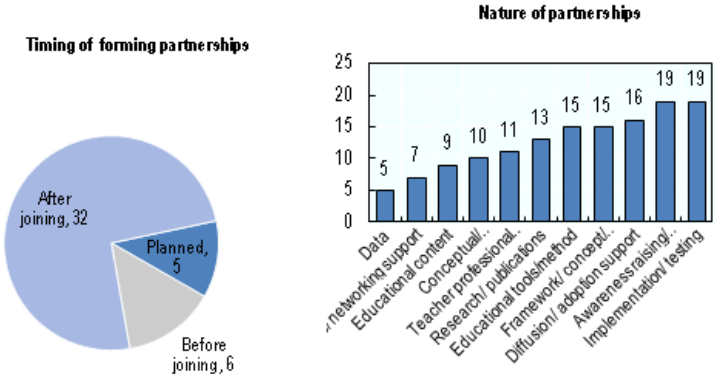
The focus of the Catalyst Initiative on international collaboration as a means to promote innovation in education finds wide resonance. Building "a networked improvement community" can be an important, targeted way to find solutions for "complex educational problems" (Bryk, Gomez and Grunow, 2010). In 1997, the Ford Foundation had already begun its Collaborating for Education Reform Initiative to improve teaching and learning in communities in the United States with emphasis on "collaborative activities designed to affect district and state education policies". The recent evaluation of the restructured Initiative suggested that "collaboratives can grow out of deliberate foundation efforts" (Bodilly, Karam and Orr, 2011). In higher education, collaboration in a consortium structure can promote transformational change beyond individual institutions and encourage innovation (Forcier, 2011).

More generally, interest among policy makers towards increasingly international "open collaborative work" is growing in the context of globalisation (OECD, 2008, 2012). "Open collaborative innovation" can be desirable for promoting social welfare (Baldwin and Von Hippel, 2009) and new knowledge production "is often a collective process involving a significant number of individuals and organisations" (OECD, 2010a). In the private sector, for example, collaboration, interaction, engagement with external agents and/or international partnerships were suggested as ways to support innovation in firms in various countries (Bakker, Oerlemans and Pretorius, 2008; Fitjar and Rodriguez-Pose, 2011; Hoveskog and Antonova, 2011).

Collaboration and testing within designed networks

Collaboration and networks offer great potential for the local and global diffusion of innovations – including in education. Collaboration can be critical not only for generating, but also spreading innovation, since "it allows [among other things] greater access to [...] opportunities for testing and trialling" (OECD, 2009). Collaborative arrangements can help expand educational offerings (Hardman, 2006) and, more generally, horizontal networks can with the right incentives be an important way of diffusing and distributing innovations by users or self-manufacturers (Von Hippel, 2003; OECD, 2004). Within the private sector, although local and non-local collaborations can "represent complementary spurs to innovation" (He and Wong, 2012), a challenge has been to benefit from emerging global innovation networks "to access new knowledge and markets" (OECD, 2010a).

Figure 4. Partnership formation within the Catalyst Initiative (43 partnerships)



Source: HP Catalyst Final and First Year Reports (2012).

The Catalyst Initiative has been effective in fostering diverse partnerships especially for further testing and dissemination of innovations in technology-supported education, often internationally (Chart 4). More than half of the projects considered that the collaboration within the Catalyst Initiative benefited them by providing contacts with potential future partners and/or grounds for future collaborative work. By late 2012, 43 substantive partnerships among Catalyst members were reported. Nearly three-quarters of these partnerships were formed after the start of the Initiative in 2010 – only a few were pre-existing, while more partnerships were at the stage of concrete planning. Almost half of the 43 partnerships had implemented and tested ideas or products, while nearly half involved awareness raising or dissemination activities (Box 7). Furthermore, the Catalyst partnerships have facilitated international testing and dissemination of educational innovations, as more than half of them crossed national boundaries – especially within consortia (Annex N). A clear majority of partnerships formed within consortia were international, while those across consortia tended to be national (Box 7 and Annex N) While most of the Catalyst partnerships comprised more than one activity, over one-third were formed for one specific purpose only. For example, most of the eight partnerships formed by the State University of New York focused on resource sharing or conceptual or methodological support.

Box 7. Partnerships within the Catalyst Initiative

International partnerships within consortia

Several projects have been using the Catalyst Initiative connections – especially within consortia – to form partnerships for implementing and testing their educational models in a range of contexts. Within the Global Collaboratory consortium, East Carolina University in the United States, made its "Virtual Computing Lab [...] test accounts and custom virtual environments" available to both the Egyptian Cairo University and Kenyan Strathmore University. Cairo University also tested and provided comments on the independent VMware Lab Manager (VLM) system of East Carolina University. Within the Measuring Learning consortium, the Indian Amrita University and the Colorado School of Mines in the United States held an Electric Field Hockey Workshop for exceptional high school students at Amrita University's summer science camp. During this workshop, an activity designed by Colorado School of Mines to measure creativity and curiosity was tested and related data was collected. Further testing and data collection was done by Rancocas Valley Regional High School in the United States. Supported by the HP Catalyst Leadership Fund, Rancocas Valley Regional High School and Mexican Universidad de las Américas Puebla also provided the Colorado School of Mines with "valuable feedback" on implementation of its InkSurvey. Within the New Learner consortium, Reach the World in the United States collaborated with the Indian Agastya Foundation and the Brazilian Center for Digital Inclusion. They had a shared mission "to spark curiosity [and] use inquiry-based learning" even though they were working with different student populations. Reach the World shared its online geography game GeoGames with the Agastya Foundation and introduced the Agastya Foundation's "peer-to-peer science educator model and the mobile lab concept" to its students while the collaboration between Reach the World and the Center for Digital Inclusion on fostering intercultural exchanges is under intensive planning. Within the Pedagogy 3.0 consortium, the University of Bristol in the United Kingdom has been collaborating with Kenyatta University in Kenya to scale up its video-based teachers' professional development model with the help of HP Catalyst Leadership Fund.

National partnership across consortia

Cross-consortia partnerships have a more national focus. For example, during the Catalyst Initiative, the French Ecole Centrale de Lyon of Measuring Learning and EMLYON Business School of STME-Preneur jointly created an IDEA Masters programme combining innovation, design, entrepreneurship and arts. The programme forms part of a larger Learning Lab initiative of the two universities that is "a 400 m² physical space designed for experimentation, collaboration, training and research on innovation in education". In autumn 2012, 31 students from diverse backgrounds entered the IDEA Masters programme after a selective process assessing their "leadership, creativity, cooperation and initiative" skills.

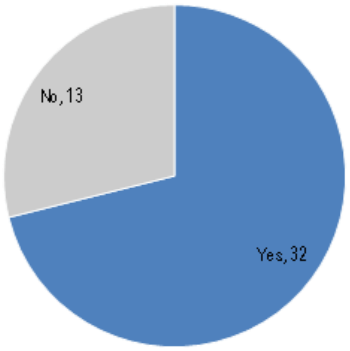
Source: HP Catalyst Final and First Year Reports 2012.

Awareness of innovations in STEM+ education has also been spreading through the network of external partners of the Catalyst members (Annex O). Catalyst members reported at least 90 external partnerships by late 2012, over half of which had been formed since the start of the Initiative. Over half of the external partners were implementing or testing ideas or products of the Catalyst members, while one-third were providing data. Over one-third of external partners received conceptual or methodological support and/or teacher professional development while another third raised awareness or disseminated information about the work of Catalyst members. A large majority of external partners were schools, higher education institutions and non-governmental organisations.

Ideas and inspiration from collaboration

Collaboration and openness can be expected to enhance innovation in terms of new ideas and inspiration. While "the most valuable knowledge" can be "hard to codify", enlarging the "base of ideas and technologies on which to draw" as well as speeding up exploitation of ideas for economic value are important benefits of open innovation (OECD, 2008, 2010a). In the context of globalisation and technological advancements, firms are increasingly collaborating with external – and more and more international – partners in order to "stay abreast of developments, [as well as to] tap into a larger base of ideas and technology" (OECD, 2010a). In spite of process challenges, the diversity of "people from different organizations work[ing] together to develop new products, services, or markets" can "positively influence collaborative knowledge creation" (Du Chatenier *et al.*, 2009). For example, collaboration with public research institutions can increase product innovation in private firms (Robin and Schubert, 2013).

Figure 5. New ideas resulting from the Catalyst Initiative collaboration or exchanges (45 projects)



Source: HP Catalyst Final and First Year Reports (2012).

The Catalyst Initiative collaboration and exchanges sparked new ideas among most of its members – paving the way for further innovation in technology-supported STEM+ education. As the most commonly cited non-financial benefit, about two-thirds of the projects considered that they benefited from the Catalyst Initiative participation a lot or a fair bit in terms of new ideas for further work (Annex P). Nearly two-thirds reported that the Catalyst collaboration or exchanges resulted in new ideas beyond their original project design (Chart 5). For example, as a result of its participation in the Beijing Catalyst summit in 2012, St. Thomas Aquinas College in the United States started exploring an idea to use its "gaming courseware as a tool to help teach English as Second Language". Following the example of the South African Meraka Institute, Kenya's Kenyatta University has been exploring the possibilities of using mobile technology to increase students' access to more learning resources. Overall, nearly half of the projects considered their own consortia to be at least a partial source of their new ideas, whereas over one-third saw them result at least partly from the collaboration with members of other consortia (Annex Q). The new

ideas generated by the Global Collaboratory and Measuring Learning consortia members in particular have resulted mainly from collaboration or exchanges within their individual consortia (Box 8).

Box 8. New ideas emerging from the Catalyst within consortia collaboration and exchanges

New ideas within the Global Collaboratory consortium

Collaboration and exchanges through the Catalyst Initiative has led to emergence of new ideas and diffusion of old ones within the Global Collaboratory consortium. In late 2012, the entire Global Collaboratory consortium was preparing a collaborative book comprising case studies based on individual projects. Meanwhile, face-to-face events had led the University of Washington in the United States and Masindo Muliro University of Science and Technology in Kenya to plan new collaborative work building on their ongoing activities. Working on a university-secondary school vertical integration programme in science, Masindo Muliro University of Science and Technology wished to "identify ways to make [its] program more sustainable by reducing inefficiencies and increasing its broader impact". The main challenge was the lack of "facility that could serve as a local hub for the train-the-teacher sessions and host the Catalyst equipment". Working on experiential and contextual learning in construction and architecture, University of Washington wanted to "design diverse experiences for its students [...] and to increase diversity among [the] student population". The challenge was to provide the students with experiences such as "designing and constructing buildings in remote locations" as well as to "outreach and inform a broader base of students on built environment career paths". To better serve their needs, the two institutions planned to merge their respective educational models for the construction of a laboratory supported by the HP Catalyst Leadership Fund. Coventry University in the United Kingdom was also planning to design an online platform to support the initial "messy talk" stages of design consultations – "messy talk" being a concept of the construction engineering work of University of Washington.

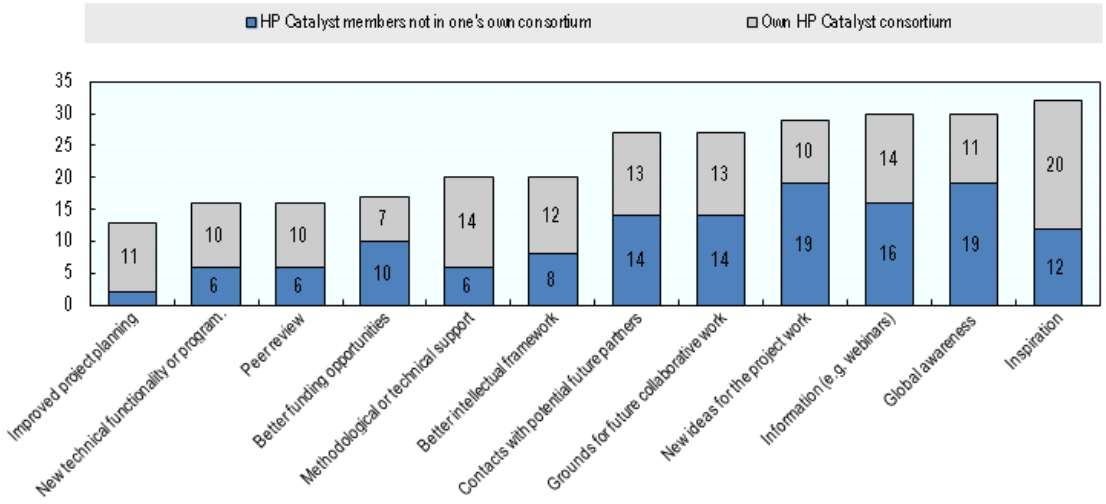
New ideas within the Measuring Learning consortium

The Catalyst Initiative has also helped further development and dissemination of ideas within the Measuring Learning consortium. Following the international conference in Beijing in 2012, Colorado School of Mines was invited to give an international workshop for exceptional high school students at a science camp organised by Amrita University, a fellow member of the Measuring Learning consortium. As a result, Colorado School of Mines "designed an activity using electric field hockey to attempt to measure the creativity [...] and the curiosity that was sparked" during the science camp. Unlike most of the university's other Catalyst work, this did not rely on the use of InkSurvey due to hardware restrictions. In addition, French Ecole Centrale de Lyon – another Measuring Learning member – has been considering possibilities of using InkSurvey for creativity assessment in the multidisciplinary IDEA programme it has built together with French EMLYON Business School.

Source: HP Catalyst Final and First Year Data 2012.

The greatest benefit that emerged from the Catalyst collaboration and exchanges was inspiration (Chart 6 and Annex Q). Collaboration inspired the work of over two-thirds of the projects – particularly within consortia such as Pedagogy 3.0. For example, the University of Nigeria greatly appreciated the "encouragement and inspiration" from the Pedagogy 3.0 consortium leader and learning about similar challenges other projects working on teacher professional development were having. Face-to-face meetings of the Measuring Learning consortium helped Russia's National Research Irkutsk State Technical University to rethink its MoPS collaborative platform development in terms of student creativity. The Computer History Museum in the United States, part of the New Learner consortium, reports that "one of [its] primary motivations for applying to the Catalyst Initiative was the prospect of joining a consortium of like-minded educators who aspire to transform STEM+ education in and out of schools". The Catalyst involvement has led the museum to integrate STEM+ education into the "core strategic goals for the institution as a whole". Overall, half of the Catalyst projects considered that the larger STEM+ education framework was among the three most important strengths of the Initiative.

Figure 6. Perceived benefits of collaboration within the Catalyst Initiative (46 projects)



Source: HP Catalyst Final and First Year Reports (2012).

Other important advantages that emerged were gaining a global perspective and new information (Chart 6 and Annex Q). More than half of the projects chose international scope as one of the three most important strengths of the whole Catalyst Initiative. Nearly two-thirds of the projects – especially those within the Multi-Versity consortium – reported benefiting from better global awareness and/or information. For example, Kenyatta University in Kenya started to "think globally rather than locally" and to expand its horizons as to what was possible in integrating technology in education. Collaboration within the Pedagogy 3.0 consortium helped the university to discover that some other projects with similar focus "had advanced beyond [its] initial targets". These projects then provided Kenyatta University with "questions and solutions that [it was] able to use […] without reinventing the wheel". Coventry University found that the Catalyst Initiative has greatly expanded its opportunities to collaborate worldwide, beyond European borders. Its "conceptualisation of teaching and learning" was also informed by linking "with other researchers working in a similar field and finding overlaps in research, and sharing literature". The National University in the United States, primarily a teaching institution, appreciated the opportunity provided to connect with several research institutions. The Agastya Foundation, leader of the New Learner consortium notes that one important lesson from the collaboration was that challenges and solutions tend to be "similar in most of the projects' locations".

Capacity through support and collaboration

Collaboration and involvement in networks can not only enhance financial sustainability, but also help build skills and competence for innovation and in education. Essentially, collaboration can support innovation by enabling "greater access to [...] capabilities and resources" (OECD, 2009). In the private sector, accessing "specific skills and competences" and finding "complementary expertise" can be one of the drivers for firms to collaborate more with external partners in the context of globalisation and technological advancements (OECD, 2010a). Historically, for example, university research collaboration "contributed to the development of in-house research capabilities" of pharmaceutical firms in the 1920s and 1940s in the United States (Furman and MacGarvie, 2009).

In terms of sustainability, the Catalyst network supported members to acquire further resources for innovative work on technology-enhanced STEM+ education. Over a quarter of the Catalyst projects have been successful in attracting further resources for their work and report that this is at least partly due to their participation in the Catalyst Initiative (Annex R). A few more had built on their Catalyst involvement

to apply further funding, but did not yet know whether they had been successful or not by the late 2012. In total, Catalyst members have attracted over USD 9 million of further funding, of which over USD 8.1 million was garnered by the Ecole Centrale de Lyon and EMLYON Business School from the French government (Box 9). Two other projects attracted further funding for over USD 200 000 from the US National Science Foundation and one more over USD 50 000 from the European Union. The rest of the smaller donations – less than USD 50 000– were obtained mostly from private firms and foundations or from the internal funds of institutions. Some projects also obtained in-kind support at least partly due to the Initiative, for example in the form of volunteers, technology or of free software licences. Overall, more than half of the Catalyst members considered that their work benefited a lot or a fair bit from better possibilities for further funding due to participation in the Initiative (Annex P). Over one-third of projects saw collaboration in particular as beneficial in terms of better funding opportunities (Chart 6).

Box 9. Leveraging the Catalyst Initiative for further resources

Several projects have successfully leveraged the Catalyst Initiative to build up their STEM+ education innovations to a point where they start receiving wider attention and further financial support. The French Ecole Centrale de Lyon and EMLYON Business School were awarded a six year competitive governmental grant of roughly USD 8.1 million for pedagogical experimentation work under their joint Learning Lab and IDEA programme initiated during the Catalyst Initiative. Being part of the international Catalyst network and a letter of support from the Vice President of HP France also helped secure the funds. The Colorado School of Mines has attracted over USD 450 000 in further support for its work on real-time formative assessment – mainly through several competitive grants from the National Science Foundation (NSF). Attracting these funds "would have been impossible without the support [...] received from the HP Catalyst Initiative". Western Michigan University, also in the United States, considers that its achievements in developing virtual laboratories under the Catalyst Initiative helped it to gain a USD 260 000 competitive grant from the NSF. Coventry University attracted over USD 70 000 in additional funds – most from the Lifelong Learning Program of the European Union – and considers that without the initial support for sustaining pedagogical research on the built environment its "faculty would not be in a position to even make these bids". The State University of New York was awarded an Innovation Generation grant amounting to almost USD 50 000 from Motorola Solutions Foundation after mentioning "the receipt of the Catalyst grant as background" in its application and receiving feedback from the HP team for its proposal.

Source: HP Catalyst Final and First Year Data, 2012.

In addition to direct funding, involvement in the Catalyst helped some projects gain credibility, and administrative and political support. For example, the Colorado School of Mines considers that the Initiative has provided its work on real-time formative assessment with "a solid pedagogical foundation, sufficient tantalizing evidence [...] and credibility that [it] heretofore lacked in the educational research community". For the EMLYON Business School, working on multidisciplinary pedagogical innovation, having HP as an early donor "has been crucial for the project credibility" and helpful in gaining support from other stakeholders. The Computer History Museum in the United States has used its Catalyst participation to gain "administrative support for [the] partner teachers" implementing its inquiry-based, collaborative and technology-driven STEM program.

The Catalyst collaboration and exchanges also provided several projects with opportunities for peer learning (Chart 6). Over one-third of the projects found the collaboration, particularly within consortia, benefited their work by providing them with better intellectual frameworks and/or methodological or technological support. Roughly one-third benefited from peer review and/or new technical functionality or programme components. Collaboration helped about a quarter of members to improve their project planning. For example, the leader of the Measuring Learning consortium helped the Colorado School of Mines to improve its project planning, clarify its intellectual framework and renew the focus of its project on real-time formative assessment and creativity. Feedback and methodological and technical information from weekly meetings of the Pedagogy 3.0 consortium helped Beijing Normal University in China to improve its project plan for teacher professional development for technology integration. As to cross-

consortium support, Russia's National Research Irkutsk State Technical University received help from China's University of Geosciences – an associate member – for platform approbation and the review of its MoPS collaborative educational model. In the United States, teachers at Stamford Public Schools working on internationally collaborative and project-based science learning received professional development from the experts of Northern Arizona University, an associate Catalyst member.

LESSONS FOR DESIGNING COLLABORATIVE INNOVATION PROGRAMMES

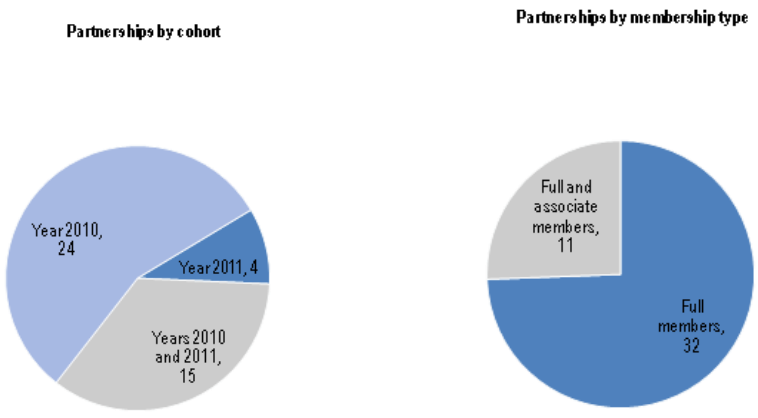
Several lessons can be drawn from the HP Catalyst Initiative by those aiming to stimulate educational innovation through collaboration. The Initiative was carefully designed and adopted a set of good practices such as evaluation and coaching. Its thorough monitoring generated a significant amount of data for learning (Annex B). Studying the work and organisation of the Initiative provide new insights into collaborative innovation and the steps that should be considered in order to maximise the success of similar grant programmes. This section presents key features of the Catalyst Initiative's design and implementation and draws lessons that may be useful to government policy makers, foundation leaders and other stakeholders seeking to design a collaborative innovation programmes.

Boost collaborative innovation by early face-to-face interactions and targeted funding

The strong and explicit emphasis on international collaboration and network creation was a strength of the Catalyst Initiative. Collaboration helped to spark new ideas and inspiration and built capacity among many of its members (Chart 4, 5 and 6).

By 2012, virtually all Catalyst members across consortia had participated in some collaborative activities and perceived it as beneficial for their work (Annex S and T). Collaboration was most commonly selected as the most important strength of the Catalyst Initiative, by one-quarter of the projects. More than half identified collaboration and/or international scope as among the Initiative's three most important strengths. Expanding the possibilities for collaboration yet further was identified as the most desirable further development of the Catalyst Initiative with over half of the projects selecting adding to existing collaboration as among the three most important future improvements.

Figure 7. Partnership formation by Catalyst membership status (43 partnerships)



Source: HP Catalyst Final and First Year Reports (2012).

The Catalyst Initiative shows that fostering collaboration requires time. A good structure helps, but time is required to develop collaboration successfully, and perhaps build interpersonal trust and understanding. Comparison of the 2010 and 2011 cohorts demonstrates that the longer-lived cohorts developed collaboration further (Chart 7). More than half of the 43 Catalyst partnerships were formed and planned exclusively between 2010 cohort members, against one-third taking place between members of the 2010 and 2011 cohorts, some of which already existed before the Initiative. Only a few partnerships took place within the 2011 cohort alone. Although roughly half of the 2011 cohort full members were involved in at least one Catalyst partnership by late 2012, this was the case for 80% of the 2010 cohort. Of the six consortia, partnership participation was most modest within the STEM-Preneur consortium (Annex N) – likely reflecting its latecomer membership of 2011 cohort projects.

Catalyst members also found that time was a major factor in other ways in building collaboration. In general, lack of time for collaboration was seen as one of the five challenges for collaboration by over half of the projects (Annex U). The greatest challenge was seen as organising collaboration across time zones. According to one consortium leader, time constraints "forced a trade-off between [...] face-to-face meetings [essential to create a momentum and] follow-up work [...] essential to maintain this momentum". Consortium leaders typically already had responsible roles in their own organisations with the consortium work forming an additional responsibility. While one-to-one meetings with each project leader were very useful for "getting to know the projects and members and to help build relationships between them", finding the time for this was a challenge. When it came to Catalyst projects, they may have found it difficult "to maintain their commitment to the global collaboration due to shortage of time and commitment to deliver their individual projects".

Face-to-face meetings and events had a significant positive impact on building relationships and collaboration among Catalyst members. The monitoring by ISTE clearly showed that collaboration particularly took off after the first face-to-face international conference in New Delhi in 2011, six months after the launch of the Initiative, and peaked again after the Beijing conference in 2012.[8] In line with this, virtually all projects selected the international conferences as among the five most important factors supporting collaboration (Annex U) – both within and outside the consortia. More than half indicated the importance of the face-to-face consortia meetings held in late 2011 or early 2012 in supporting collaboration within their own consortium. Conversely, over one-third saw lack of face-to-face contact as a challenge to collaboration within consortia. In general, face-to-face meetings were reported to be among the three most important strengths of the Catalyst Initiative by over one-third of its members, while over half suggested the provision of more opportunities for face-to-face contacts to further improve the Initiative (Annex T). Face-to-face interactions can be particularly important for building engagement, interest and trust – essential ingredients for successful collaboration (Annex U). Nearly half of the projects chose interest and engagement to be an important factor supporting the Catalyst collaboration, while about one-third chose trust among members. Face-to-face contacts may also eventually help promote collaboration via digital means such as online communities, virtual conferences or e-mails.

Collaboration within the Catalyst Initiative can also partly be traced back to the provision of specifically targeted resources. These took the form of innovation funds, leadership awards and mini-grants supporting attendance at non-Catalyst face-to-face meetings. The analysis shows that partnership formation is associated with full member status: the large majority of the 43 Catalyst partnerships were formed or planned by full members alone, with only one-quarter combining full and associate members (Chart 7). While 35 full members and 3 consortia leaders were reported to be involved in at least 1 Catalyst partnerships by late 2012, this was the case for only 7 associate members. Cash awards from the Innovation and Leadership Funds fostered Catalyst collaboration by some associate members – the three associate members that were involved in more than one partnership were either recipients of the cash awards or collaborating with a recipient. In addition, over one-third of full members considered that the

Innovation and/or Leadership Funds, worth from USD 10 000 to 100 000, supported collaboration within the Catalyst Initiative.

We recommend that all initiatives wanting to enhance innovation in education through collaboration facilitate early and sufficient face-to-face contact and consider providing incentives for collaboration through targeted funding. Collaborative endeavours should be launched with early face-to-face meetings of network members allowing them to share information as well as to build trust, interest and engagement. Early face-to-face contact also provides an effective way for network members to explore possible partnerships. In retrospect, the Catalyst members would have benefited from an international conference scheduled as soon as practically possible after the launch of the 2010 cohort so the consortium work could launch with face-to-face meetings. Collaborative work among network members should also be supported with targeted funding where possible. In addition, organisations taking part in the collaboration should be provided with enough resources to secure the time needed for collaborative activities.

Provide support to build capacity for quality, efficiency and sustainability

Supporting collaboration, further project management and methodological support were good practices of the Catalyst Initiative. Over half of the Catalyst members reported that their work benefited a lot or a fair bit from collaboration support provided by HP and ISTE. Nearly half considered that their work benefited a lot or a fair bit from the project management and/or methodological support from HP or ISTE (Annex P) – including training, regular coaching and feedback (Box 10). Support from ISTE/ HP was selected as being one of the three most important strengths of the Catalyst Initiative by one-third of projects, and one-third wished this support to be increased in the future (Annex T). Among consortium leaders, one leader noted a clear need to support projects "to express their ideas in ways that could be understood by others" – for example through "elevator pitches", policy relevance or multimedia presentations. Similarly, the evaluation of Ford Foundation's Collaborating for Education Reform proposed provision of "stronger management support" and "training in grant writing and fundraising" as potential improvements for the initiative (Bodilly, Karam and Orr, 2011).

Box 10. Capacity building within the Catalyst Initiative

The capacity building incorporated in the framework of the Catalyst Initiative supported the work of several projects. For example, Kenyatta University in Kenya – working on technology integration through professional development of teachers – considered that after support from HP and ISTE the team was "better informed about managing a project of [that] magnitude" and better equipped to write grant proposals for further funding". Support from ISTE assisted the State University of New York to develop stronger grant proposals in collaboration with other Catalyst members. The university's teacher professional development work also benefited from resources such as workshops and regular phone consultations with an HP employee acting as an Catalyst ambassador. Renmin University of China greatly appreciated the regular support ISTE provided for their everyday work and the feedback from the monthly follow-up reports. Encouraged by "ISTE and HP to look at sustainability and scalability", Conestoga College in Canada has started to share its experiences with technology-enhanced teaching elsewhere in the college. Northwestern University in the United States and Thompson Rivers University in Canada – both working on online laboratories – benefited from HP/NMC social medial training, the latter also finding "the strategies presented for networking and exploring possibilities for outside funding [...] quite helpful".

Source: HP Catalyst Final and First Year Reports, 2012.

Support for capacity building has been an integral part of the Catalyst Initiative from the start (Annex F). The Catalyst consortia leaders and projects were given training on the collaboration and dissemination of information in the early days of the Initiative. ISTE provided the projects with continuous coaching and organised several thematic webinars. For example, projects were helped to define their research questions, methodology and impact measurement as well as provided with support in preparing

grant proposals. A wide range of materials relevant to project planning and outcome measurement were made available to the projects. ISTE also regularly monitored project progress through regular status surveys and subsequently shared the analysis with Catalyst members for feedback. NMC supported the projects in communication and dissemination, for example through specific Catalyst web pages. Moreover, the HP Ambassador Initiative was launched in 2012 to assign specific HP employees to provide coaching and advice to selected Catalyst projects. HP also helped the projects to seek further funding – for example by providing them with support letters to include in their grant applications – and the HP Sustainability and Social Innovation office kept close ongoing contact with the Catalyst members.

We recommend that initiatives aiming to enhance innovation in education incorporate regular capacity building in their design. The support should address project design and outcome measurement, together with tools for project management and communication. The support could take the form of specific training, resource sharing and individual coaching. Regular monitoring and feedback can help improve quality and efficiency of the grantee work, providing that it does not become too frequent and burdensome. It should also be noted that one consideration when organising collaborative programmes is to find a good balance between building capacity for collaboration and creating a dependency on the support offered by the programme.

Use monitoring and feedback for adjustment and improvement

A constant search for improvement was another strength of the Catalyst Initiative. A regular monitoring and feedback structure allowed the outputs and outcomes of a funding initiative to be assessed upon its completion, but also allowed it to be the adapted and improved as it was implemented when needed.

Willingness to learn and improve was part of the Catalyst Initiative from the start. The Initiative set up a body of Executive Advisors to get feedback through monthly phone conferences and meetings taking place each semester. For example, the OECD was invited to follow the Initiative from the start as an Executive Advisor and an independent critical friend with a view to improving the next rounds of the Initiative and drawing wider lessons from its work. Data were collected throughout the process and indicators were set to measure the success and impact of the Initiative (Annex B and C). ISTE monitored the progress of Catalyst projects and their collaboration through brief monthly surveys. This report draws largely on more comprehensive status reports submitted by the projects at the beginning, middle and end of their grant period. The consortium leaders attended monthly conference calls and were asked to report regularly on the progress of their consortium's work (Annex F).

The feedback received from the monitoring was used to fine tune and improve the Catalyst Initiative. For example, consortia were provided with opportunities to organise face-to-face meetings once it became clear that interactions in person were essential to foster collaboration effectively. A new online platform for collaboration was launched to replace the initial one that was only modestly used by the Catalyst members. The Innovation Fund was launched in 2011 and the Leadership Fund in 2012 to accelerate the success of projects and provide resources for further collaboration and dissemination (Annex F). A specific website was launched and related training provided to help projects disseminate their findings and increase their visibility. After analysis of the first data sets, the data collection framework was revised to adapt it better to development and improvement work (Annex B).

We recommend that initiatives which aim to enhance innovation in education use regular monitoring and feedback to adjust and improve their implementation. The monitoring and feedback should include regular data collection and dissemination of the subsequent analysis. It is also important to establish an external advisory group to provide independent, critical and constructive feedback for the initiative.

Define consortia in detail or allow free consortium formation to enhance collaborative innovation

One of the strengths of the consortium structure of the Catalyst Initiative was that it helped provide the space in which collaborative innovation could develop. As might be expected, the benefits of collaboration were perceived to be stronger within rather than across consortia. In many ways, this highlights the success of the strategy of developing collaboration within a consortium of consortia. Nearly two-thirds of the projects considered that their work benefited a lot or a fair bit from collaboration within their consortium, while one-third estimated that this was the case for collaboration outside their consortium (Annex P). The consortia were particularly conducive to forming international partnerships among the Catalyst members and subsequently to dissemination and testing of technology-supported educational innovations in different cultural contexts (Box 7 and Annex N). Within consortia, collaboration served also as a source of new ideas and peer capacity building (Chart 6 and Annex Q). Overall, the consortium structure was seen as one of the three top strengths of the Catalyst Initiative by a quarter of the projects (Annex T).

On the other hand, the consortium structure presented challenges. The intentional diversity of consortia members seems to have sometimes slowed down collaboration. A third of the projects chose clarifying of the consortium structure and themes as one of the top three improvement needs for the Catalyst Initiative (Annex T) after expanded possibilities of collaboration and more opportunities for face-to-face interactions. A quarter of the projects suggested changing the model for collaboration. Moreover, the benefits from collaboration within consortia were unevenly distributed. Whereas at least three quarters of the Multi-Versity and Measuring Learning members reported benefiting a lot or a fair bit from collaboration within their own consortium, this was the case for less than a half of the STEM-Preneur and New Learner members (Annex Q).

This heterogeneity can partly be traced back to the Catalyst selection process (Annex E). The selection process was based on an international Request for Proposals, a traditional, competitive selection by a jury of experts. After HP had defined the consortium themes with the help of education advisors and ISTE, projects were requested to apply to a specific consortium as opposed to the Catalyst Initiative as a whole. Projects were not reassigned across consortia after the selection process, it was simply decided whether their application to a specific consortium was to be funded or not. The selection criteria put a strong emphasis on the reach of the projects – they had to serve a minimum of 2 000 secondary or higher education students – and on their geographical spread worldwide. Preference was given to projects that served disadvantaged students under-represented in STEM professions, were engaged in other relevant networks and had already received funding. The applicants were requested to submit a description of how they would measure their results. The selection resulted in 50 very diverse projects considered to be complementary.

Across the six consortia, the diversity encompassed different themes, objectives, disciplines, education levels and countries covered (Chart 1 and Annex D, I and J). Some projects within the same consortium were conducting early stage product development, while others were validating previous work or disseminating already developed resources to very large target populations (Annex D and K). The size of the consortia varied from 6 to 11 full members and covered anywhere between 4 and 7 countries (Box 1).

Another source of diversity was the loose definition of the Catalyst consortia themes (Box 1 and Annex E). In order to create space for innovation, HP chose to initially define consortia by themes and guiding questions included in the call for proposal. As the themes were open ended in nature, the selection process led to a wide diversity of projects within some consortia. A few projects could have fit into many different consortia and several cross-cutting themes – such as educational gaming or online laboratories – emerged across the Catalyst Initiative (Annex D). The first task of the consortia, once launched, was to

refine the guiding questions, collaboration objectives, and specific outputs and outcomes. HP was not prescriptive about how consortia should develop their work, but they applied project management discipline through ITSE to ensure that activity took place. Through NMC HP added layers of activity, such as video recording and webinars to build and maintain activity around the programme.

Given the loose definition of the themes, more homogeneous consortia or different leadership styles may have helped to speed up collaboration. Although over one-third of the projects considered that shared goals or themes supported collaboration within consortia, about one-quarter saw lack of them, insufficient co-ordination and/or lack of clarity about the framework as a challenge for collaboration (Annex U). For example, one consortium leader noted that "collaboration can take place only if [two] or more parties anticipate their own projects can be advanced through collaboration" – encouragement alone being insufficient.

The leadership styles of consortium leaders also played a role in the speed of collaboration efforts and in overcoming the challenge of heterogeneity within consortia. For instance, shared goals or themes were seen as a factor supporting collaboration by at least half of the Multi-Versity and Measuring Learning members, whereas over half of the STEM-Preneur and Global Collaboratory members found that a lack of shared goals or themes was challenging collaboration within their consortia (Annex U). Consortia probably need different types of leadership, and also time commitment of their consortium leader, depending on their degree of heterogeneity and how specific their theme is. While leadership with ability to "promote shared goals among members" can significantly influence collaborative effort (Bodilly, Karam and Orr, 2011), the six consortium leaders are likely to have used different leadership styles (Annex G). One leader highlighted that managing a consortium requires a variety of skills, credible expertise and the right attitude. The skills leaders need are "leadership, inter-personal, coordination, organisation, and administrative skills" as well as "the ability to organise and lead a workshop". Credible expertise requires expertise within the subject area "including a background in STEM subjects, innovation, digital media and learning/technology enhanced learning" as well as the ability to "build relationships between people". As to attitudes, the consortia leaders would also need to be "comfortable living with ambiguity" since "there is a need for judgment throughout on the balance between nurturing new ideas and focusing on outcomes".

Consequently, the balance between project heterogeneity, specificity of consortium themes, and type of consortium leadership is an important consideration in designing a collaborative innovation programme. In the case of the Catalyst, the mix of these ingredients may sometimes have slowed down the choosing of common objectives and areas of work by the consortia members as well as collaboration. Those designing such a programme could also consider alternative approaches to those used by the Catalyst Initiative. For instance they could consider being more prescriptive about the goals and objectives of the consortia. This approach might lead to quicker convergence on specific consortium collaborative outputs when consortia are very heterogeneous. Conversely, they could consider giving no thematic guidance and let consortia define their collaborative work. This approach was tested by the Fulbright New Century Scholar programme initiated and funded by the US Department of State. In the case of the Catalyst Initiative consortium leaders and members may have felt that their freedom to define their own collaborative work was limited by the pre-definition of the consortia themes. A third possible approach, which is used by the European Commission for its framework programmes, is to ask organisations to apply as pre-formed consortia with a specific, predefined collaborative innovation or research project. This approach is perhaps less conducive to unexpected partnerships and serendipity.

We recommend that initiatives aiming to promote innovation in education through collaboration use a consortium structure and carefully consider different approaches when defining it, including two contrasting ones:

- *Tighter definition of the consortia in advance.* More specific objectives and expected outcomes of the consortia could be defined prior to the selection process. The consortia members would then be selected based on their compatibility with the pre-defined objectives and outcomes – with the consortium leaders playing an important role in the selection process. Without necessarily pre-empting innovation and serendipity, this approach would increase coherence and accelerate collaboration owing to an early understanding of each project's role within the consortium. This approach would require a significant time investment in defining the consortia objectives and expected outcomes before the launch of the initiative. Under this approach, the initiative would probably benefit from consortium leaders with strong project management skills.

- *Defining the consortia after they are formed*. Projects could be selected on their merit according to a predefined mix of project types, but with no definition of consortia themes. The consortia, their objectives, outputs and outcomes could then be freely formed and defined by the members themselves, taking into account the characteristics and specific contributions of their projects. This approach would enable a free – and perhaps unexpected – design of the consortia and their work. It may be particularly suitable for initiatives aiming to promote open-ended innovation in education. This approach would probably need to rely on leaders that are able to make connections and have enough time to understand the details of each project within their consortium.

Make a detailed overview of projects characteristics at the start to facilitate collaboration

Trying to organise collaboration so that it starts quickly is an important issue in designing collaborative grant programmes such as the Catalyst Initiative. In addition to the structure of the Initiative and targeted funds for collaboration, gathering rich information may help projects to accelerate collaboration, especially when projects do not belong to the same consortium.

The first meeting of the Catalyst Initiative took place in Washington DC in October 2010. At the meeting, consortium leaders, the HP team and other advisors set the Initiative objectives, started to build collaborative relationships between leadership organisations, and allowed leaders to explore possible connections between the projects within their consortia. This early mapping helped to get a sense of the diversity of the projects and plan collaboration activities.

A more detailed, analytical overview of the different projects and consortium characteristics was established at the Initiative level following interim reporting (Annex B). It provided a better understanding of the details of the diversity of the Catalyst Initiative. For example, this is when it became clear that the overall focus of the Catalyst Initiative was on development activities instead of research validation, which helped to adjust the outcome expectations and the monitoring framework.

Providing a detailed overview of project diversity as early as practically possible may be another way to accelerate collaboration. In the case of the Catalyst Initiative, this overview information could have been used more to shape and accelerate collaboration among projects above and beyond consortium collaboration as well as to target more capacity-building support. For example, supplementary networks of related projects such as those working on online laboratories could have been encouraged. Projects with similar types of work, methods or interests could have been connected earlier. A consortium leader for example suggested that a "more explicit [...] linking of projects working on similar objectives in similar contexts" would have been useful. The design of the first reporting questionnaires would also have been more appropriate as validation and development projects require different types of evaluation and monitoring.

The overall approach of the Catalyst Initiative was that self organisation would lead to a more effective and "organic" network, so that projects should find and organise their partnerships themselves. In this context, the detailed overview was undertaken for monitoring purposes rather than for boosting collaboration.

As the collaboration process takes time, we recommend that initiatives aiming to promote innovation in education through collaboration carry out an early, detailed overview of the participants' characteristics and use this information to shape collaboration along several dimensions. The mapping could clearly identify not only the themes of the projects, but also other substantive aspects of their work such as their objectives and their expected outputs and outcomes. Ideally, it should start with and be used during the selection process. To ease the analytical process, an online application form or the baseline reporting questionnaire could ask applicants/participants to place themselves into different project categories. Otherwise, such an overview could be done by a systematic, comparative analysis of the project proposals, which typically include this information. In addition to specific substantive themes, the projects could be mapped according to the type of work they intend to carry out, which might include development and improvement, validation and measurement or scaling up and disseminating already validated ideas, practices or products. Depending on the nature of the initiative, the projects could also be categorised according to educational objectives such as access, equity, efficiency, satisfaction and student learning outcomes – comprising technical, but also social, behavioural, thinking and creativity skills.

Communicate the monitoring and evaluation metrics early on

It can be a challenge to formulate a monitoring and evaluation framework that accommodates exploratory innovation with adequate assessment. The purpose of monitoring is to document the initiative and that of evaluation to provide feedback on its success and success conditions. Clear evaluation metrics allow the collection of adequate baseline information at the start and subsequently support learning from the initiative.

Communicating the monitoring and evaluation metrics early on encourages all participants to achieve good measures on the selected indicators. While this supports the achievement of the measured objectives, it can also hinder the evaluation of the projects, at least for objectives that can be easily manipulated. Transparency about these metrics should thus be seen as an integral part of the initiative design.

Yet, formulating adequate monitoring and evaluation metrics can be particularly difficult when aiming to foster open-ended exploratory innovation. Defining which outcomes of individual innovative projects should be monitored can take time, the most relevant outcomes to be measured can change over time and the traditional outcome measures may turn out to be inappropriate. While this calls for flexibility regarding substantive outcomes at project, consortium and initiative levels, the challenge is less pressing for evaluation of collaboration or sustainability outcomes.

The Catalyst Initiative took monitoring and evaluation seriously. The consortia were asked to set their objectives and metrics themselves. HP also developed metrics for the Catalyst Initiative as a whole. The full set of indicators was released after consultation with project and consortium leaders. However, the process might have been enhanced had the overall indicators of success been communicated earlier on to the projects and consortia leaders, even though the Catalyst Initiative regularly monitored the progress towards substantive, collaboration and sustainability outcomes (Annex C).

Clearer and a more consistently communicated emphasis on the need for substantive evidence of project outcomes might have improved data collection on the final outcomes of the Catalyst projects (Annex B). Although most projects recorded a positive impact of their work on various education and innovation outcomes in their final report, fewer provided sufficient explanation and evidence to support

their claims, including when their findings were available as publications. It is therefore difficult to assess whether some projects did not adequately report their achievements or if they were unsuccessful in their work. Finding the right incentives or the right reporting format for projects to report their results is another challenge for collaborative innovation programmes.

We recommend that initiatives aiming to promote innovation in education define and communicate their monitoring and evaluation metrics in sufficient detail early on. While the framework should retain some flexibility for innovative, unpredicted outcomes, it can still generally include indicators on basic educational outcomes of access, equity, efficiency, satisfaction and student learning – in terms of technical, social, behavioural, thinking and creativity skills. In the case of the Catalyst Initiative, analysis of the rather open-ended baseline data provided invaluable support for the development of a more appropriate and fine-tuned final reporting framework.

Consider possibilities for comparative evaluation in the design of the initiative

Evaluating the overall impact of a collaborative initiative such as the Catalyst Initiative can be challenging. An important question is whether collaborative funding initiatives in general produce better results than initiatives that do not promote collaboration among individual grantees. Another question is whether some dimensions of the initiative design could be improved for the future. Evaluating whether the outputs and outcomes of the initiative would have been different with a different design is very difficult without comparison groups or programmes – the existence of a plausible counterfactual. An appropriate comparison group could not be found in the Catalyst Initiative.

Another difficulty lies in the fact that the impact of collaborative initiatives may continue well after the grantees are still members of such initiative. Whatever the impact during the lifetime of the grant, where collaborative relationships have developed and continue to be sustained, positive outcomes may continue well beyond the initiative's lifetime and outside its defined aims and objectives.

A third challenge for evaluating projects such as the Catalyst Initiative lies in their continuous striving for improvement. Continuous change makes it particularly difficult to ascribe an effect to a particular cause or feature of the programme.

Dependent on the practicalities, we recommend that initiatives aiming to promote innovation in education through collaboration consider some additional options to evaluate their overall added value and the impact of different features of their organisation. They should consider three additional possibilities for evaluation:

- *Identify an external comparison group*. Although difficult, the collaborative initiatives could explore identifying an external, similar enough comparison group. For example, in the case of the Catalyst, the Initiative explored the possibility of comparing the 50 funded projects with the 29 associate projects or with other projects funded on an individual basis, but this was eventually seen as not relevant. It also considered the possibility of comparing substantive outcomes and partnerships with the outcomes of other research projects previously funded by HP, but this was ultimately not possible for practical reasons.

- *Create an internal comparison group*. In order to evaluate the impact of some aspects of the Initiative, large endeavours can create some variations in their design. For example, they could choose to define consortium themes in advance for some groups of projects, and after formation for others. To evaluate the impact of different communication types, some consortia or projects could rely more on face-to-face interactions while others would use more video conferences and

online platforms. More generally, initiatives could create variations in selection, support or participation conditions between consortia or projects.

- *Build on comparison over time*. Another possibility would be to evaluate the initiative by comparing its different rounds over time. This would require that the design and selection criteria – and thus initial characteristics of the projects –not to vary excessively between different rounds.

CONCLUSION

The work of the Catalyst Initiative highlights the potential of technology-supported innovation in many STEM disciplines and different cultural contexts, especially in higher and secondary education. Technology-supported innovations such as educational gaming, online laboratories, technology-supported collaboration, real-time formative assessment and skills-based assessment can improve STEM education in many different ways.

- *Diverse teaching and learning.* Interactive and reactive educational gaming – video games, simulations or virtual worlds – enables a wide range of experimentation and learning by doing. Online laboratories can enable lower-cost, flexible access to experimental learning, allowing increased study time not restricted by timetable or location. Technology can also significantly increase opportunities for collaborations across cultures and between distant locations, and enable students to collaborate beyond formal classroom hours. Real-time formative assessment allows teachers to monitor student learning as it happens and immediately adjust their teaching to the needs of students.

- *Diverse and adequate assessment.* Real-time formative assessment provides avenues for assessing different types of activities and various student skills such as problem-solving or creativity. Technology can help measure different skills for innovation through approaches such as essays, blogs or virtual learning environments.

- *Improved student learning*. Educational gaming can increase students' achievement and subject-specific knowledge, while online laboratories can help support student understanding and achievement at least as well as physical hands-on experiments. Technology-enabled collaboration may support student learning, in terms of both individual and group outcomes. Real-time formative assessment can increase student achievement by promoting reflection by students about their learning needs and their engagement in their own learning.

- *Better student interaction, engagement and motivation.* Educational gaming based on play and increasing challenges can foster engagement and motivation. Technology-enabled collaboration can encourage student group work, interaction and engagement.

- *Enhanced higher-order skills.* Educational gaming may improve skills such as problem solving. Providing instantaneous feedback through real-time formative assessment may also enhance skills such as problem solving or creativity.

The Catalyst experiences suggest that several factors need to be considered and addressed when promoting the adoption of technology-supported innovations in education. These include both the context and the resources available.

- *Context.* Context counts when promoting the adoption of technology-supported innovations in education. In order to be adopted, innovations need to be responsive to local needs and adjust to existing educational structures such as the curriculum. Opportunities to use existing networks and contacts should be used. Moreover, people in the context matter too – the ability to spark or rely on the interest and engagement of students, teachers and other stakeholders is essential. In addition, the existing competency level of teachers and students can make a difference in attempts to introduce technology-supported innovations in education at a large scale.

- *Resources*. Adopting technology-supported innovations in education requires adequate material, human and intangible resources. As well as educational content, having adequate infrastructure, hardware and software in place is vital. Furthermore, adopting technology-supported innovations in education needs sufficient technical support, teacher training and means of providing feedback. Intangible resources such as giving staff sufficient time, and providing administrative and other support can also prove important for success.

The case of the Catalyst Initiative illustrates how collaboration and active support can help spread, accelerate and sustain development of innovations in education:

- *Dissemination.* Initiatives with an explicit emphasis on international collaboration can increase partnerships and networking for further testing and dissemination of educational innovations.

- *Acceleration.* Promoting international collaboration within a set framework can spark new, unexpected ideas and inspiration.

- *Sustainability.* Collaborative initiatives with active support structures can help sustain and build capacity for innovation in education through increased financial possibilities, credibility and enhanced human capital.

Finally, lessons can be learned from the strengths and challenges of the Catalyst Initiative for those aiming to stimulate innovation in education in the future:

- *Collaboration.* Boost collaborative innovation by early face-to-face interactions and targeted funding.

- *Capacity support.* Provide support to build capacity in research project management, evaluation, communication and fund raising for quality, efficiency and sustainability.

- *Monitoring and feedback.* Use monitoring and feedback for adjustment and improvement.

- *Adequate consortia.* Either define consortia in detail or allow free consortia formation to enhance collaborative innovation.

- *Information mapping.* Map project objectives, methods and expected outputs at the start to facilitate collaboration.

- *Timely communication.* Communicate the monitoring and evaluation metrics early on.

- *Comparative evaluation.* Consider comparative evaluation in the design of the initiative.

NOTES

[1] See the HP Catalyst Initiative: *http://www8.hp.com/us/en/hp-information/social-innovation/catalyst.html*

[2] The GDM features were well received by higher education students. Self-reported data from the Sustainability course using GDM suggests that students perceived features such as "linking the 'game creation' homework activity to the team's 'research project'" to be an "effective and synergetic approach" (4.24 on scale 1-5 with 5 been the most favourable). Students on the Computer Ethics course also viewed the

features of GDM positively – with "learning course material through game creation, playing (demonstration) is an effective method of learning" (4.17), "team presentation & game demo is an effective method to communicate with the class" (4.17) and "learning was fun through 'game creation and play'"(4.17).

[3] Both teacher and student perceptions on the iLab remote laboratories and their features have been positive. In videos, interviews and surveys, teachers have positively noted the focus on process in iLab remote laboratories, highlighting also the importance of increasing access to students that may not otherwise have access to scientific experiments. The probe ware kit resources accompanying the remote laboratories have been seen as accurate and usable in many contexts, while offering also real-time, high-resolution data for analysis (HP Catalyst Final Data, 2012). Remote online laboratories and similar simulated laboratories were also compared in a recent study based on structured interviews with undergraduate higher education psychology students in the Northwestern University. The study suggests that students using remote laboratories "more naturally questioned their results", implying more authentic inquiry and understanding. Students appreciated the real-hands on laboratory feeling achieved with the help of the webcam, expressed trust in the data and were personally invested in ensuring data quality (Sauter *et al.*, 2013).

[4] Both teachers and students have had a positive impression on the features and usefulness of the OLab online laboratories and CAPPS overall. Majority of the 49 teachers providing feedback on a CAPSS workshop found that OLabs simulated the actual laboratory environment (70%), the performance of which was seen as excellent or very good (84%). Most teachers found the system useful (93%), online laboratory website easy to use (79%) and reported of getting a clear understanding of the experiment and related topics (89%) (HP Catalyst First Year Data, 2012). Amrita University's online laboratory simulations and animations for mathematics and science had already been compared with the traditional laboratory experience in an earlier study. Student feedback and assessment suggested that most "students preferred the ease of use, adaptive feedback and additional learning options of the adaptive simulations", although they "missed the group discussions and extra attention from the teacher at the traditional" laboratory (Nedungadi and Raman, 2010).

[5] The project-based and technology-enhanced collaborative learning module has been well received by the students. The share of satisfied students has increased by 17% points from the previous year. This refers to the share of students choosing "definitely agree" or "mostly agree" to a statement "overall quality of this module is satisfactory" in the teaching evaluation questionnaire of Coventry University, identical to previous year.

[6] A survey of student perceptions of online collaborative learning suggested that the Zask discussions make sense (78%) and students wish to further participate in online discussions (77%). Yet, half of students considered that "the online time is limited and is difficult to be guaranteed".

[7] Students thought online learning could "expand the amount of information and their own knowledge" (92%) as well as "enhance learning and emotional exchange" (90%). Most also believed "that collaborative learning activities contribute to better master relevant skills" (95%) and "could adapt and identify the model of online collaborative learning combined with traditional teaching and learning" (83%). As to factors impacting online collaborative learning, most students "affirmed the importance of participation of teachers" (97%) and though "that other' active participation and timely feedback could help capture great perception of affection and affiliation" (98%).

[8] Every month, the individual HP Catalyst Initiative grantees were asked to submit Collaboration Meter Reports administered by ISTE. These short reports include both closed and open-ended questions on collaboration with the other grantees as well as on the status of project implementation.

REFERENCES

Akinsola, M.K. and I.A. Animasahun (2007), "The Effect of Simulation-Games Environment on Students Achievement in and Attitudes to Mathematics in Secondary Schools", *Turkish Online Journal of Educational Technology*, Vol. 6, No. 3.

Aldrich, C. (2009), "Virtual Worlds, Simulations, and Games for Education: A Unifying View", *Innovate: Journal of Online Education*, Vol. 5, No. 5.

Almarshoud, A.F. (2011), "The Advancement in Using Remote Laboratories in Electrical Engineering Education: A Review", *European Journal of Engineering Education*, Vol. 36, No. 5.

Altamirano, N. and J. Jaurez (2012), "Student Built Games in Economic Courses: Applying the Game Design Methodology as Another Approach to Deeper Learning", paper and presentation at the American Economic Association – 2nd National Conference on Teaching Economics, Boston, 30 May and 1 June 2012.

Ananiadou, K. and M. Claro (2009), "21st Century Skills and Competences for New Millennium Learners in OECD Countries", *OECD Education Working Papers*, No. 41, OECD Publishing.

Annetta, L.A., J. Minogue, S.Y. Holmes and M. Cheng (2009), "Investigating the Impact of Video Games on High School Students' Engagement and Learning About Genetics", *Computers & Education*, Vol. 53, No. 1.

Avvisati, F. and S. Vincent-Lancrin (forthcoming), "Effective Teaching for Improving Students' Motivation, Curiosity, and Self-Confidence in Science", *OECD Education Working Paper* (forthcoming), OECD Publishing.

Bai, H., W. Pan, A. Hirumi and M. Kebritchi (2012), "Assessing the Effectiveness of a 3-D Instructional Game on Improving Mathematics Achievement and Motivation of Middle School Students", *British Journal of Educational Technology*, Vol. 43, No. 6.

Bakker, R.M., L.A.G. Oerlemans and T. Pretorius (2008), "Domestic and International Innovation Partnerships: Do They Matter for Innovation Outcomes of South African Firms?", *South African Journal of Economics*, Vol. 76, No. 3.

Baldwin, C.Y. and E. Von Hippel (2009), 'Modeling a Paradigm Shift: From Producer Innovation to User and Open Collaborative Innovation", *Harvard Business School Working Paper* 10-038, Harvard Business School.

Bodilly, S., R. Karam and N. Orr (2011), *Continuing Challenges and Potential for Collaborative Approaches to Education Reform*, RAND Corporation, Santa Monica.

Briggs, C.L. and D. Keyek-Franssen (2010), "Clickers and CATs: Using Learner Response Systems for Formative Assessments in the Classroom", *EDUCAUSE Quarterly*, Vol. 33, No. 4.

Bryk, A.S., L.M. Gomez and A. Grunow (2010), *Getting Ideas into Action: Building Networked Improvement Communities in Education*, Carnegie Perspectives, Carnegie Foundation for the Advancement of Teaching, Stanford.

Burd, S., A. Seazzu and C. Conway (2009), "Virtual Computing Laboratories: A Case Study with Comparisons to Physical Computing Laboratories", *Journal of Information Technology Education*, Vol. 8.

Chini, J., A. Madsen, E. Gire, N.S. Rebello and S. Puntambekar (2012), "Exploration of Factors that Affect the Comparative Effectiveness of Physical and Virtual Manipulatives in an Undergraduate Laboratory", *Physical Review Special Topics – Physics Education Research Journal Citation*, Vol. 8, No. 1.

Darling-Hammond, L. (1998), "Policy and Change: Getting Beyond Bureaucracy" in A. Hargreaves, A. Lieberman, M. Fullan and D. Hopkins (eds.), *International Handbook of Educational Change*, Kluwer Academic Publishers, Dordrecht.

Dede, C. (2006), "Scaling Up: Evolving Innovations Beyond Ideal Settings to Challenging Contexts of Practice" in R.K. Sawyer (ed.), *The Cambridge Handbook of Learning Sciences*, Cambridge University Press.

Crawley, C., P. Gerhard, A. Gilleran and A. Joyce (2008), "eTwinning: Adventures in Language and Culture", *Handbook*, Central Support Service for eTwinning and European Schoolnet, Brussels.

Du Chatenier, E., J.A.A.M. Verstegen, H.J.A. Biemans, M. Mulder and O. Omta (2009), "The Challenges of Collaborative Knowledge Creation in Open Innovation Teams", *Human Resource Development Review*, Vol. 8, No. 3.

Enriquez, A. (2010), "Enhancing Student Performance Using Tablet Computers", *College Teaching*, Vol. 58, No. 3.

European Schoolnet (2013), *Survey of Schools: ICT in Education. Benchmarking Access, Use and Attitudes to Technology in Europe's Schools*, European Schoolnet, Brussels.

Fitjar, R.D. and A. Rodriguez-Pose (2011), "Firm Collaboration and Modes of Innovation in Norway", *Centre for Economic Policies Research Discussion Papers*, Centre for Economic Policies.

Flint, S. and T. Stewart (2010), "Food Microbiology – Design and Testing of a Virtual Laboratory Exercise", *Journal of Food Science Education*, Vol. 9, No. 4.

Forcier, M.F. (2011), "Innovation Through Collaboration: New Pathways to Success", *Trusteeship*, Vol. 19, No. 5.

Fullan, M. (2007), *The New Meaning of Educational Change*, Teachers College Press, New York.

Furman, J.L. and M. MacGarvie (2009), "Academic Collaboration and Organizational Innovation: The Development of Research Capabilities in the US Pharmaceutical Industry", *Industrial and Corporate Change*, Vol. 18, No. 5.

Gardner, T.Q., S.E. Kowalski and F.V. Kowalski (2012), "Interactive Simulations Coupled with Realtime Formative Assessment to Enhance Student Learning", in *ASEE 2012 Conference and Exposition Proceedings*, San Antonio, Texas.

Gok, T. (2012),"Real-Time Assessment of Problem-Solving of Physics Students Using Computer-Based Technology", *Hacettepe University Journal of Education*, Vol. 43.

Grimley, M., R. Green, T. Nilsen and D. Thompson (2012), "Comparing Computer Game and Traditional Lecture Using Experience Ratings from High and Low Achieving Students", *Australasian Journal of Educational Technology*, Vol. 28, No. 4.

Gutierrez-Cuba, J.V., A. López-Malo and E. Palou (2012), "Graduate Student Perspectives on Using Tablet PCs and Associated Technologies", *Proceedings of the 2012 American Society for Engineering Education Annual Meeting*, San Antonio, Texas.

Hardman, J. (2006), *Collaborating for Success: Collaborative Arrangements for 14-19 Provision in the West Midlands. Summary and Analysis of Research Findings from Six Case Studies*, Learning and Skills Development Agency Research Report, Learning and Skills Network, London.

He, Z. and P. Wong (2012), "Reaching Out and Reaching Within: A Study of the Relationship between Innovation Collaboration and Innovation Performance", *Industry and Innovation*, Vol. 19, No. 7.

Hennessy, S. and L. London (2013), "Learning from International Experiences with Interactive Whiteboards: The Role of Professional Development in Integrating the Technology", *OECD Education Working Paper*, No. 89, OECD Publishing.

Hoveskog, M. and D. Antonova (2011), "Collaboration and Innovation in Sweden and Bulgaria: A Study of a Mature Industry", *International Journal of Economic Sciences and Applied Research*, Vol. 4, No. 1.

Jara, C., F.A. Candelas, S.T. Puente and F. Torres. (2011), "Hands-on Experiences of Undergraduate Students in Automatics and Robotics Using a Virtual and Remote Laboratory", *Computers & Education*, Vol. 57, No. 4.

Jaurez, J., P. Fu, R. Uhlig and S. Viswanathan (2010), "Beyond Simulation: Student-Built Virtual Reality Games for Cellular Network Design", in *Proceedings of American Society for Engineering Education Conference and Exhibition*, Louisville, Kentucky.

Jona, K., R. Roque, J. Skolnik, D. Uttal, and D. Rapp (2011), "Are Remote Labs Worth the Cost? Insights from a Study of Student Perceptions of Remote Labs", *International Journal of Online Engineering*, Vol. 7, No. 2.

Jona, K. and Vondracek, M. (2013), "A Remote Radioactivity Experiment", *The Physics Teacher*, Vol. 51, No. 151.

Kärkkäinen, K. (2012), "Bringing about Curriculum Innovations: Implicit Approaches in the OECD Area", *OECD Education Working Papers*, No. 82, OECD Publishing.

Karpova, E., A. Correia and E. Baran (2009), "Learn to Use and Use to Learn: Technology in Virtual Collaboration Experience", *Internet and Higher Education*, Vol. 12, No. 1.

Kelly, D., J. Baxter and A. Anderson (2012), "Engaging First-Year Students through Online Collaborative Assessments", *Journal of Computer Assisted Learning*, Vol. 26, No. 6.

Kohl, P.B., H.V. Kuo, S. Kowalski, and F. Kowalski (2011), "Promoting and Assessing Creativity and Innovation in Physics Undergraduates", *Proceedings of the 2011 Physics Education Research Conference*, August 2011, Omaha, Nebraska.

Ku, H., T. Ahfock and T. Yusaf (2011), "Remote Access Laboratories in Australia and Europe", *European Journal of Engineering Education*, Vol. 36, No. 3.

Lin, K.Y., J.W. Son and E. Rojas (2011), "Safety Director: A 3D Game Environment for Construction Safety Education", *Journal of Information Technology in Construction* (ITCON), 2011 special issue "Use of Gaming and Virtual World technology in Architecture, Engineering and Construction".

Looney, J.W. (2011a), "Integrating Formative and Summative Assessment: Progress toward a Seamless System?", *OECD Education Working Papers*, No. 58, OECD Publishing.

Looney, J.W. (2011b), "Alignment in Complex Education Systems: Achieving Balance and Coherence", *OECD Education Working Papers*, No. 64, OECD Publishing.

Looney, J.W. (2009), "Assessment and Innovation in Education", *OECD Education Working Papers*, No. 24, OECD Publishing.

Nedungadi, P. and R. Raman (2011), "Learning-Enabled Computer Assessment of Science Labs with Scaffolds Methodology", *The Technology Interface International Journal*, Vol. 11, No. 2.

Nedungadi, P. and R. Raman (2010), "Effectiveness of Adaptive Learning with Interactive Animations and Simulations", *3rd International Conference on Advanced Computer Theory and Engineering (ICACTE)*, Vol. 6.

Nevgi, A., P. Virtanen and H. Niemi (2006), "Supporting Students to Develop Collaborative Learning Skills in Technology-Based Environments", *British Journal of Educational Technology*, Vol. 37, No. 6.

Nussbaum, M., C. Alvarez, A. McFarlane, F. Gomez, S. Claro and D. Radovic (2009), "Technology as Small Group Face-to-Face Collaborative Scaffolding", *Computers & Education*, Vol. 52, No. 1.

OECD (2012), *OECD Science, Technology and Industry Outlook 2012*, OECD Publishing.

OECD (2010a), *The OECD Innovation Strategy: Getting a Head Start on Tomorrow*, OECD Publishing.

OECD (2010b), *The Nature of Learning: Using Research to Inspire Practice*, OECD Publishing.

OECD (2009), *Working Out Change: Systemic Innovation in Vocational Education and Training*, OECD Publishing.

OECD (2008), *Open Innovation in Global Networks*, OECD Publishing.

OECD (2005), *Formative Assessment: Improving Learning in Secondary Classrooms*, OECD Publishing.

OECD (2004), *Innovation in the Knowledge Economy – Implications for Education and Learning*, OECD Publishing.

OECD/Eurostat (2005), *Oslo Manual: Guidelines for Collecting and Interpreting Innovation Data*, OECD Publishing.

Olympiou, G. and Z. Zacharia (2012), "Blending Physical and Virtual Manipulatives: An Effort to Improve Students' Conceptual Understanding through Science Laboratory Experimentation", *Science Education*, Vol. 96, No. 1.

Palou, E., Gazca, J.A. Díaz García, J.A. Rojas Lobato, L.G. Guerrero Ojeda, J.F. Tamborero Arnal, M.T. Jiménez Munguía, A. López-Malo, J.M. Garibay (2012), "High-Quality Learning Environments for Engineering Design: Using Tablet PCs and Guidelines from Research on How People Learn", *International Journal of Food Studies*, Vol. 1, No. 1.

Papastergiou, M. (2009), "Digital Game-Based Learning in High School Computer Science Education: Impact on Educational Effectiveness and Student Motivation", *Computers & Education*, Vol. 52, No. 1.

Prensky, M. (2008), "Students as Designers and Creators of Educational Computer Games: Who Else?", *British Journal of Educational Technology*, Vol. 39, No. 6.

Pyatt, K. and R. Sims, (2012), "Virtual and Physical Experimentation in Inquiry-Based Science Labs: Attitudes, Performance and Access", *Journal of Science Education and Technology*, Vol. 21, No. 1.

Raju, P, V. Ahmed and C. Anumba (2011), "Use of Gaming and Virtual World Technology in Architecture, Engineering and Construction", *Journal of Information Technology in Construction (ITCON)*, Special Issue Vol. 16.

Ramirez Apud, N. *et al*. (2012), "Implementing Problem-Solving Learning Environments in a Kinetics and Homogeneous Reactor Design Course", *Proceedings of the 2012 American Society for Engineering Education Annual Meeting*, San Antonio, Texas.

Ramirez-Corona, N. *et al.* (2013), "Assessing Metacognitive Awareness during Problem-Solving in a Kinetics and Homogeneous Reactor Design Course", *Proceedings of the 2013 American Society for Engineering Education Annual Meeting*, Atlanta, Georgia.

Rautenbach, J.V. and C. Black-Hughes (2012), "Bridging the Hemispheres through the Use of Technology: International Collaboration in Social Work Training", *Journal of Social Work Education*, Vol. 48, No. 4.

Resta, P. and T. Laferriere (2007), "Technology in Support of Collaborative Learning", *Educational Psychology Review*, Vol. 19, No. 1.

Robin, S. and T. Schubert (2013), "Cooperation with Public Research Institutions and Success in Innovation: Evidence from France and Germany", *Research Policy*, Vol. 42, No. 1.

Rogers, C.P. (2011), "Shaping Global Citizens: Technology Enhanced Intercultural Collaboration and Transformation", Educational Technology, Vol. 51, No. 2.

Sauter, M., D. Uttal, D. Rapp, M. Downing, and K. Jona (2013), "Getting Real: The Authenticity of Remote Labs and Simulations for Science Learning", *Distance Education Journal*.

Shaffer, D.W. (forthcoming), "Universities of Play: Games and the Future of Higher Education", in *Higher Education to 2030 (Vol. 3): Technology*, (forthcoming) OECD Paris.

Slavin, R.E. (2010), "Co-operative Learning: What Makes Group-work Work?" in H. Dumont, D. Istance and F. Benavides (eds.), *The Nature of Learning: Using Research to Inspire Practice*, OECD Publishing.

Snyder, J., F. Bolin and K. Zumwalt (1992), "Curriculum Implementation" in P.W. Jackson (ed.), *Handbook of Research on Curriculum*, Macmillan, New York.

Tasiopoulou, E. and B. Schwarzenbacher (2011), "Good Practices Report", Delivery D2.2.: Results, European Schoolnet, Brussels.

Thompson, L. and H. Ku (2010), "Degree of Online Collaboration and Team Performance: A Case Study", *Quarterly Review of Distance Education*, Vol. 11, No. 2.

Toner, P. (2011), "Workforce Skills and Innovation: An Overview of Major Themes in the Literature", *OECD Education Working Paper*, No. 55, OECD Publications.

Tutty, J.I. and J.D. Klein (2008), "Computer-Mediated Instruction: A comparison of Online and Face-to-Face Collaboration", *Educational Technology Research and Development*, Vol. 56, No. 2.

Universidad de las Américas Puebla (forthcoming a), "Analysis of Student Perspectives on Using Tablet PCs in Junior and Senior Level Chemical Engineering Courses", paper submitted to the 2013 American Society for Engineering Education Annual Meeting.

Universidad de las Américas Puebla (forthcoming b), "Assessing Metacognitive Awareness during Problem-Solving in a Kinetics and Homogeneous Reactor Design Course", paper submitted to the 2013 American Society for Engineering Education Annual Meeting.

Von Hippel, E. (2003), "Open Source Projects as Horizontal Innovation Networks – By and For Users", *MIT Sloan School of Management Working Papers* No. 4366-02, Massachusetts Institute of Technology.

Vos, N., H.V.D. Meijden and E. Denessen (2011), "Effects of Constructing Versus Playing an Educational Game on Student Motivation and Deep Learning Strategy Use", *Computers & Education*, Vol. 56, No. 1.

Wang, M. (2010), "Online Collaboration and Offline Interaction between Students Using Asynchronous Tools in Blended Learning", *Australasian Journal of Educational Technology*, Vol. 26, No. 6.

Wastiau, P., C. Kearney and W. Van den Berghe (2009), "How Are Digital Games Used in Schools? Complete Results of the Study", Final Report, European Schoolnet, Brussels.

Wu, P., G. Hwang, M. Milrad, H. Ke and Y. Huang (2012), "An Innovative Concept Map Approach for Improving Students' Learning Performance with an Instant Feedback Mechanism", *British Journal of Educational Technology*, Vol. 43, No. 2.

Yang, K. and J. Heh (2007), "The Impact of Internet Virtual Physics Laboratory Instruction on the Achievement in Physics, Science Process Skills and Computer Attitudes of 10th-Grade Students", *Journal of Science Education and Technology*, Vol. 16, No. 5.

Yang, Y.C. (2012), "Building Virtual Cities, Inspiring Intelligent Citizens: Digital Games for Developing Students' Problem Solving and Learning Motivation", *Computers & Education*, Vol. 59, No. 2.

Yien, J., C. Hung, G. Hwang and Y. Lin (2011), "A Game-Based Learning Approach to Improving Students' Learning Achievements in a Nutrition Course", *Turkish Online Journal of Educational Technology – TOJET*, Vol. 10, No. 2.

Zhu, C., M. Valcke and T. Schellens (2009), "A Cross-Cultural Study of Online Collaborative Learning", *Multicultural Education & Technology Journal*, Vol. 3, No. 1.

Zhu, C. (2012), "Student Satisfaction, Performance, and Knowledge Construction in Online Collaborative Learning", *Educational Technology & Society*, Vol. 15, No. 1.

ANNEX A – THE CATALYST INITIATIVE AS PART OF THE HP COMPANY STRATEGY

The Catalyst Initiative is a strategic education programme of the Hewlett Packard (HP) Sustainability and Social Innovation team, the philanthropic arm of HP. For HP, social innovation means developing innovative solutions to global challenges, while increasing the company's understanding of future customer needs. It sees technology, collaboration and capacity building as important to enable innovation to address critical social needs in areas like education, health, environment and community. Towards this end, HP is forming partnerships with several intergovernmental, non-governmental and private organisations with an international scope.

Education has been a key focus area for HP since its founders, Dave Packard and Bill Hewlett, made their first donation to local schools in 1939. Today, HP´s mission in education is to empower millions of students, teachers and entrepreneurs to succeed in the 21st century.

The main difference between the Catalyst Initiative and previous HP education grant schemes is its strong emphasis on collaboration. For example, the two-year Innovations in Education grant programme of 2009 supported innovative science, technology, engineering and mathematics (STEM) education pilot initiatives in 153 secondary and higher education institutions in 28 countries.[1] While the programme addressed themes including capacity building for leadership through networking and digital learning environments, it did not explicitly target collaboration among the grantees. This was also the case with the previous grant programmes of 2003 and 2004-08 that supported the effective use of technology for learning in more than 1 200 primary, secondary and higher education institutions in 41 countries.[2]

NOTES

[1] HP Innovations in Education Grant Year 2 Summary Report by ISTE: *www.hp.com/go/socialinnovationeducation*.

[2] HP Sustainability and Social Innovation.

ANNEX B – DATA

The analysis in this report builds mainly on extensive quantitative and qualitative data collected from the Catalyst projects over the past two years. The project reporting consisted of a questionnaire comprising mainly closed questions, complemented by a narrative report including open-ended questions. The closed-question online questionnaire was meant to provide a summary of the Catalyst Initiative as a whole. It included questions on the project characteristics, target populations, various data such as development, students, teacher, dissemination and sustainability outcomes, collaboration, and general feedback on the Catalyst Initiative. The purpose of the open-ended narrative report was to gather more in-depth information on project activities and achievements, including evidence for their substantive achievements in a Word document. The closed-question questionnaire and the open-ended questions of the narrative report were developed by the OECD in collaboration with HP and the International Society for Technology in Education (ISTE). The mainly narrative project data collected in 2011 formed a good base for developing a questionnaire and reporting template that took into account the specific needs of the Catalyst Initiative.

ISTE administered the data collection in autumn 2012 and it attracted high response rates. A total of 30 Catalyst grantees who had been selected for the Initiative in 2010 were asked to submit final year reports. Altogether, 26 projects completed the closed-questions questionnaire and 22 submitted the narrative report. At the same time, the 20 Catalyst grantees who had been selected in 2011 were asked to submit first year reports that were very nearly identical to the final year reports of the 2010 cohort. All 20 projects submitted both the questionnaire and narrative part of the report. That meant a total of 46 out of the 50 Catalyst projects provided the mainly quantitative closed-question data, while 42 projects provided narrative reports.

Data quality was a challenge for the analysis. In particular there were discrepancies between the closed-question and narrative part of the reports. For example, although most projects indicated that their work had had a positive impact on various education and innovation outcomes in the closed-question questionnaire, fewer provided enough explanation and evidence to support their claims in the narrative part. While the quantitative data was cleaned and corrected to reflect narrative reporting when possible, it is difficult to know whether these projects had simply failed to adequately report their achievements or were overstating their success.

When appropriate, the analysis was supplemented by a variety of quantitative and qualitative data.

- *Consortium reports*. The leaders of the six Catalyst consortia were asked to reply to open-ended questionnaires by third quarter of 2011 and again by third quarter of 2012. These reports provided information on the nature of the different consortia as well as more global impressions of collaboration and capacity building with the Catalyst Initiative. By autumn 2011 and 2012, reports had been received from four consortium leaders. The 2011 consortium report template was developed by the OECD, ISTE and HP, and the 2012 report by ISTE and HP. The data collection was administered by ISTE.

- *Baseline questionnaires.* All 50 Catalyst grantees were asked to reply to baseline questionnaires on their STEM education projects during second and third quarters of 2011. The questionnaires'

closed and open-ended questions mapped starting points, goals, expected outcomes, target groups, concrete contributions and measures used by the grantees. By autumn 2011, 48 Catalyst grantees had replied. The baseline questionnaire was developed jointly by the OECD, ISTE and HP while data collection was administered by ISTE.

- *First year reports of the 2010 cohort*. The 30 Catalyst grantees selected for the Initiative in 2010 were asked to submit first year reports during autumn 2011. These reports comprised mainly narrative information about the preliminary outcomes of the project interventions as well as their perceptions of the Initiative itself, including the elements of collaboration and capacity building. By autumn 2011, 29 Catalyst grantees had replied. The report template was developed jointly by the OECD, ISTE and HP while data collection was administered by ISTE.

- *Background documentation*. A range of background documentation was made available to depict the overall nature, background and structure of the Catalyst Initiative. The most important of these were the 2010 and 2011 Request for Proposals.[1] The background information on the Initiative was verified by the HP Sustainability and Social Innovation team, which provided additional information as well.

- *Informal follow-up.* As an executive advisor, the OECD has had the opportunity to closely follow the overall developments of the Catalyst Initiative. These observations have also supported this analysis.

NOTES

[1] See HP Catalyst Request for Proposals 2010: *www.hp.com/hpinfo/grants/docs/HP-Catalyst-Initiative-RFP.pdf* and 2011: *www.hp.com/hpinfo/grants/docs/HP-Catalyst-Initiative-2011-RFP.pdf.*

ANNEX C – EVALUATION METRICS OF THE CATALYST INITIATIVE

HP developed an evaluation framework that covered three dimensions of achievement at the three levels of the Catalyst Initiative (Table C.1). This "metrics matrix", considered the outcomes for STEM+ teaching and learning at the project, consortium and overall initiative level as well as those for collaboration and capacity building.

Table C.1. Catalyst Initiative metrics by level of activity

		Level of activity		
		Project	*Consortium*	*Catalyst*
Outcomes to be measured	*STEM+ education*	What are the project outcome measures and stories?	What outcomes happened because of consortia structure?	What outcomes spill into the world as a result of the broader impact of the Initiative?
	Collaboration	What partnerships have projects developed?	What collaboration has been developed within and across consortia?	How has collaboration extended beyond the Catalyst network?
	Capacity	Have projects attracted additional funding and resources?	Have collaborative partners successfully received additional funding and resources?	Is there greater investment and interest in the Innovation Fund?

Source: The HP Catalyst Initiative background material 2011.

ANNEX D – CATALYST MEMBERS BY CONSORTIA.

Table D.1. Members of the Global Collaboratory Consortium

Global Collaboratory led by Meraka Institute (South Africa, Gauteng) Focus on opportunities to foster international collaboration and spread best practices in STEM+ education								
Full members								
Organisation			***Activity***			***Target***		
Cohort	*Name*	*Location*	*Main focus*	*Main type*	*Location(s)*	*Population(s)*	*Education level(s)*	*Dicipline(s)*
2010	East Carolina University	United States (North Carolina)	Online laboratories	Development	United States (North Carolina)	Students (200)	Higher	Technology
2010	Masinde Muliro University of Science and Technology	Kenya	Online laboratories	Development	Kenya	Students (127) - In-service teachers (6) - Pre-service teachers (6) - University faculty (2)	Higher - Lower secondary	Science - Technology - Other/ multiple
2010	Stamford Public Schools	United States (Connecticut)	Collaborative learning	Improvement	United States (Connecticut)	Students (800) - In-service teachers (10)	Lower secondary	Other/ multiple
2010	Coventry University	United Kingdom	Collaborative learning	Improvement	United Kingdom, Canada	Students (286)	Higher	Science - Engineering
2010	Del Mar College	United States (Texas)	Community-based learning	Initial scale-up	United States (Texas)	Students (90)	Upper secondary	Technology
2010	Cairo University	Egypt	m	m	m	m	m	m
2011	University of Washington	United States (Washington)	Educational gaming	Improvement	United States (Washington)	Students (55)	Higher	Technology - Engineering
Associate members								
2010 cohort: China University of Geosciences (China, Beijing), Strathmore University (Kenya), Westerly Public Schools (United States, Rhode Island) 2011 cohort: Russian Academy of Sciences (Russia, Moscow)								

Table D.2. Members of the Measuring Learning Consortium

Measuring Learning led by Carnegie Mellon University (United States, Pennsylvania)

Focus on innovative approaches to assessing STEM+ knowledge and skills, with a strong emphasis on real-time technology-based assessments

Full members

Organisation			*Activity*			*Target*		
Cohort	*Name*	*Location*	*Main focus*	*Main type*	*Location(s)*	*Population(s)*	*Education level(s)*	*Dicipline(s)*
2010	National Research Irkutsk State Technical University	Russia (Irkutsk Oblast)	Collaborative learning	Development	Russia	Students (50) - In-service teachers - University faculty (3)	Higher	Other/ multiple - Not discipline specific
2010	Hong Kong University of Science and Technology	China (Hong Kong)	Real-time formative assessment	Development	China (Hong Kong)	Students (m) - University faculty (10)	Higher	Technology
2010	Colorado School of Mines	United States (Colorado)	Real-time formative assessment	Validation	United States (Colorado)	Students (978) - In-service teachers (15) - University faculty (20)	Higher - Upper secondary - Lower secondary	Science - Engineering - Mathematics - Other/ multiple - Not discipline specific
2010	Rancocas Valley Regional High School	United States (New Jersey)	Real-time formative assessment	Validation	United States (New Jersey)	Students (1060) - Teacher educators (11)	Upper secondary	Science - Mathematics
2010	North-West University	South Africa (Gauteng)	Curriculum / resources	Development	South Africa (Gauteng)	Students (60)	Higher	Computer science
2010	Ecole Centrale de Lyon	France	Curriculum / resources	Large-scale expansion	France	Students (751) - In-service teachers (55) - Other (15)	Higher	Engineering - Other/ multiple
2011	Universidad de las Américas Puebla	Mexico (Puebla)	Curriculum / resources	Development	Mexico (Puebla)	Students (40)	Higher	Engineering
2011	Amrita University	India (Kerala)	Curriculum / resources	Large-scale expansion	India (Kerala, Tamil Nadu, Maharashtra)	Students (45 000)	Upper secondary	Science

Associate members

2010 cohort: Rose-Hulman Institute of Technology (United States, Indiana), University of Science and Arts of Oklahoma (United States, Oklahoma), Grove City College (United States, Pennsylvania), Clemson University (United States, South Carolina), Western Governors University (United States, Utah)

2011 cohort: Griffith University (Australia, Queensland), Albemarle County Public Schools (United States, Virginia)

Table D.3. Members of the Multi-Versity Consortium

Full members								
Organisation			***Activity***			***Target***		
Cohort	*Name*	*Location*	*Main focus*	*Main type*	*Location(s)*	*Population(s)*	*Education level(s)*	*Dicipline(s)*
2010	Northwestern University	United States (Illinois)	Online laboratories	Development	United States (Illinois)	Students (600) - In-service teachers (18) - Pre-service teachers (800)	Upper secondary - Lower secondary	Science
2010	Western Washington University	United States (Washington)	Online laboratories	Improvement	United States (Washington)	Students (220)	Higher - Upper secondary	Science
2010	National University	United States (California)	Educational gaming	Initial scale-up	United States (California), Online	Students (300) - University faculty (10) - Workshop participants (500)	Higher - Upper secondary	Technology - Other/ multiple - Not discipline specific
2010	Renmin University of China	China (Beijing)	Collaborative learning	Improvement	China (Beijing)	Students (359)	Higher	Computer science - Not discipline specific
2010	Pontifical Catholic University of Rio de Janeiro	Brazil (Rio de Janeiro)	Distance learning	Initial scale-up	Brazil (Rio de Janeiro)	Students (500)	Higher	Engineering
2010	State University of New York	United States (New York)	Teacher professional development	Initial scale-up	United States (New York), Russia (St. Petersburg)	University faculty (43)	Higher	m
2011	FISK University	United States (MA)	Online laboratories	Improvement	United States (Tennessee)	Students (228)	Higher	Science - Mathematics - Computer science
2011	Thompson Rivers University	Canada (British Columbia)	Online laboratories	Improvement	Canada (British Columbia, Alberta), United States (Washington)	Students (532)	Higher - Lower secondary	Science
Associate members								
2010 cohort: University of Eastern Africa, Baraton (Kenya), Moscow Gymnasia (Russia, Moscow), University of KwaZulu-Natal (South Africa, KwaZulu-Natal), University of Massachusetts Lowell (United States, Massachusetts), East Carolina University (United States, North-Carolina), West Chester University of Pennsylvania (United States, Pennsylvania) 2011 cohort: Stellenbosch University (South Africa, Western Cape), Elizabeth City State University (United States, North Carolina)								

New Learner

Table D.4. Members of the New Learner Consortium

New Learner led by Agastya International Foundation (India, Karnataka) Focus on how learning in informal settings can connect better with formal school-based STEM+ education in primary and secondary education								
Full members								
Organisation			***Activity***			***Target***		
Cohort	*Name*	*Location*	*Main focus*	*Main type*	*Location(s)*	*Population(s)*	*Education level(s)*	*Dicipline(s)*
2010	Western Michigan University	United States (Michigan)	Online laboratories	Development	United States (Michigan)	Students (m)	Higher - Vocational	Engineering
2010	Reach the World	United States (New York)	Educational gaming	Validation	United States (New York)	Students (388) - In-service teachers (8)	Lower secondary	Other/ multiple
2010	India Council for Integral Education	India (Pondicherry)	Community-based learning	Development	India (Tamil Nadu)	Students (950) - In-service teachers (40) - Teacher educators (1000) - Other (450)	Higher - Upper secondary - Other/ multiple	Technology
2010	Longwood University	United States (Virginia)	Teacher professional development	Initial scale-up	United States (Virginia), Ghana, India (Tamil Nadu), South Africa (Eastern Cape)	Students (672) - In-service teachers (63)	Upper secondary - Lower secondary - Other/ multiple	Science - Technology - Other/ multiple - Not discipline specific
2010	Sheffield City Council	United Kingdom	m	m	m	m	m	m
2010	University of Fort Hare	South Africa (Eastern Cape)	m	m	South Africa (Eastern Cape)	m	Higher	m
2011	St. Thomas Aquinas College	United States (New York)	Educational gaming	Development	United States (Ohio, New York)	Students (40) - In-service teachers (5)	Upper secondary	Other/ multiple
2011	City Academy Norwich	United Kingdom	Educational gaming	Improvement	United Kingdom (England)	Students (220)	Lower secondary	Other/ multiple
2011	Computer History Museum	United States (California)	Collaborative learning	Development	United States (California), Mexico (Monterrey)	Students (43) - In-service teachers (3)	Upper secondary - Vocational	Technology
2011	Meraka Institute	South Africa (Gauteng)	Distance learning	Improvement	South Africa	Students (m)	Not specific	Mathematics
2011	Centre for Digital Inclusion	Brazil (Rio de Janeiro)	Community-based learning	Large scale expansion	Brasil (Ceará)	Students (272)	Lower secondary	Technology
Associate members								
2010 cohort: Federal Institute of Education, Science and Technology of Maranho (Brazil, Maranhão), Detroit Edison Public School Academy (United States, Michigan), World Wide Workshop Foundation (United States, New York) 2011 cohort: N/A								

Table D.5. Members of the Pedagogy 3.0 Consortium

Pedagogy 3.0 led by Futurelab (United Kingdom)

Focus on innovations in preparing teachers to accommodate STEM+ learning in secondary schools

Full members

Organisation			*Activity*			*Target*		
Cohort	*Name*	*Location*	*Main focus*	*Main type*	*Location(s)*	*Population(s)*	*Education level(s)*	*Dicipline(s)*
2010	Learning Games Network	United States (Massachusetts)	Educational gaming	Development	United States	Students (m) - In-service teachers (m)	Other/ multiple	Not discipline specific
2010	Fraunhofer Institute	Germany (Baden-Württemberg)	Distance learning	Improvement	Germany	Pre-service teachers (20)	Adult	Other/ multiple
2010	University of Bristol	United Kingdom	Teacher professional development	Development	United Kingdom (England)	Students (700) - Pre-service teachers (50)	Higher - Lower secondary	Science
2010	California State University at Dominguez Hills	United States (California)	Teacher professional development	Initial scale-up	United States (California)	Students (674)	m	m
2010	Kenyatta University	Kenya	Teacher professional development	Initial scale-up	Kenya	Students (960) - In-service teachers - Pre-service teachers (280) - University faculty (11)	Higher - Upper secondary - Adult	Other/ multiple
2010	University of Exeter	United Kingdom	m	m	m	m	m	m
2011	Beijing Normal University	China (Beijing)	Teacher professional development	Improvement	China (Beijing)	Students (50 000) - In-service teachers (500)	Higher - Lower secondary - Vocational	Mathematics
2011	California State University Northridge	United States (California)	Teacher professional development	Improvement	United States (California)	In-service teachers (53) - Pre-service teachers (80)	Higher	Science
2011	Kingston Primary School	Australia (Western Australia)	Teacher professional development	Improvement	Australia (Western Australia)	Students (170) - In-service teachers (8) - Pre-service teachers (13)	Higher - Primary	Mathematics - Not discipline specific
2011	University of Nigeria	Nigeria (Enugu)	Teacher professional development	Initial scale-up	Nigeria (Enugu)	Pre-service teachers (50) - Teacher educators (6)	Higher	Science

Associate members

2010 cohort: LSN (United Kingdom), Northern Arizona University (United States, Arizona)

2011 cohort: N/A

Table D.6. Members of the STEM-Preneur Consortium

STEM-Preneur led by Tsinghua University School of Economics and Management (China, Beijing) Focus on the possibilities of combining STEM and Entrepreneurship education								
Full members								
Organisation			***Activity***			***Target***		
Cohort	*Name*	*Location*	*Main focus*	*Main type*	*Location(s)*	*Population(s)*	*Education level(s)*	*Dicipline(s)*
2011	EMLYON Business School	France	Curriculum / resources	Development	France	Students (31) - University faculty (30)	Higher - Adult	Not discipline specific
2011	Conestoga College	Canada (Ontario)	Curriculum / resources	Development	Canada (Ontario)	Students (157)	Higher	Mathematics
2011	Texas A&M University-Kingsville	United States (Texas)	Curriculum / resources	Initial scale-up	United States (Texas)	Students (120)	Higher	Engineering
2011	Saratov State Technical University	Russia (Saratov Oblast)	Entrepreneurial education	Improvement	Russia	Students (80) - In-service teachers (15)	Higher - Vocational	Other/ multiple
2011	Learning Links Foundation	India (New Delhi)	Entrepreneurial education	Initial scale-up	India (Kerala)	Students (10) - Community service centre trainers and students (6)	Higher - Other/ multiple	Science - Other/ multiple
2011	Saint Petersburg State University	Russia (Saint Petersburg)	Entrepreneurial education	Initial scale-up	Russia (Saint Petersburg)	Students (80) - University faculty (10)	Higher	Science - Computer science
Associate members								
2010 cohort: N/A 2011 cohort: FATE Foundation (Nigeria), University of South Florida Polytechnic (United States, Florida), Southern Oregon Education School District (United States,Oregon)								

ANNEX E – SELECTION OF THE CATALYST MEMBERS

Designing the consortia and selecting the consortium leaders was one of the first steps in the planning of the Catalyst Initiative. The first five consortia were created in 2010 and they initially each included six member organisations as well as a lead organisation. In 2011, up to five additional projects were recruited to each of the original consortia – while a sixth consortium of six members was also created. The HP Sustainability and Social Innovation team defined the six consortium themes with the help of education advisors and ISTE. The first five consortia were designed to cover areas that would address strategic needs for innovation in STEM education in a majority of education systems across the world. The themes were also seen as critical for systematic "21st century" learning. Developing new types of skills requires new teaching and assessment models, while teachers need to be supported by new forms of professional development in order to change their practice. At the same time, globalisation and technology have changed the context of learning, allowing a rethink of how education is delivered, formally or informally. The sixth consortium was created to strengthen the focus on entrepreneurship within the Catalyst Initiative, enhance the relevance of STEM and build on synergies with the HP Learning Initiative for Entrepreneurs (HP LIFE).

HP identified the first five consortium leaders in early 2009 and the sixth in second quarter of 2011. The leaders were selected "by invitation" among prominent figures and researchers in online education, with due attention to geographic balance to reflect the global nature of the work. While the criteria were flexible, HP looked for organisations that were thought-leading, credible, and highly motivated.

The individual projects were selected for Catalyst membership through two competitive Requests for Proposals organised over the summer of 2010 and spring of 2011. Projects applied to join specific consortia, rather than general membership of the Catalyst Initiative. It was possible for one project to apply for several consortia at the same time, if they so wished. Each proposal was scored on its own merits. The projects were not reassigned across consortia after the selection process, it was simply decided whether their application to a specific consortium was to be accepted or not. The selection process lasted approximately four weeks, and involved a jury of experts co-ordinated by ISTE. The judges used a common rubric for scoring proposals and they provided salient comments and recommendations. These scores and comments, as well as feedback from consortium leaders, informed the final decision which was made by the HP Sustainability and Social Innovation team.

The initial 2010 round selected 30 funded projects, 6 for each consortium, and invited another 24 organisations to join as unfunded associate members distributed across the consortia. The subsequent 2011 call selected another 20 projects as full members to the Initiative: 6 for the new consortium, with the remaining 14 projects distributed among the original consortia. It also offered associate member status to a further eight organisations. Not all of the organisations invited to join as unfunded associate members ended up participating in the network. More than 300 organisations applied for the Catalyst Initiative grants, 176 of them in 2010 and another 127 in 2011, Overall, approximately 16% of the applicants were selected as full Catalyst Members. The Requests for Proposals were communicated through partner organisations such as ISTE and via HP's network of employees who are engaged with education organisations. The application period for both selection processes was roughly two months.

The selection criteria for the Catalyst Initiative in both rounds took into account organisation size, experience and geographical spread. To be eligible, applicants had to be an accredited public or private

education institution or consortium serving a minimum of 2 000 secondary or higher education students. This minimum size was fixed to avoid unbalanced investment to small organisations, but smaller organisations could submit a proposal as a part of a larger coalition. While the budget needed focus, the desire was to create bridges between innovative STEM education approaches in secondary and higher education levels. Geographically, institutions from 11 countries were eligible in 2010 – Brazil, China, Egypt, France, Germany, Kenya, India, Russia, South Africa, the United Kingdom and the United States. For the 2011 the list was modified somewhat, covering 14 countries – Australia, Brazil, Canada, China, France, Germany, India, Mexico, Nigeria, Russia, South Africa, United Arab Emirates, the United Kingdom and the United States. Eligibility was based on HP's presence in that country and marketing strategy. For both selection rounds, organisations had to show they had experience in addressing the relevant consortium theme as well as meeting minimum infrastructure and expertise requirements for the use of the award technology.

Catalyst applicants were asked to provide information about their project goals and plans in English. This included a short overview of their project, the characteristics of the student population to be targeted and a description of the research questions and innovations to be explored, including the role of technology. Applicants were also requested to submit a description of how they were planning to measure the results of their project, a timeline and information about the members of the project team, including their respective roles and experience.

Overall, the selection of the Catalyst projects reflected the need to balance different criteria. Some guidelines as to what kind of projects would be given preference were established prior to the selection process, on top of the basic eligibility criteria. Preference was given to organisations that served disadvantaged students under-represented in STEM professions. Similarly, organisations which were actively engaged in other relevant networks and already had funded projects that could be enhanced by the Catalyst Initiative were preferred in both rounds, as HP had placed collaboration as key to the Initiative's success. The 2011 selection process also gave preference to organisations in countries that would complement the existing membership of the consortia.

ANNEX F – CATALYST INITIATIVE SUPPORT FRAMEWORK

Since 2010, the HP Sustainability and Social Innovation team has committed more than USD 14 million to the Catalyst Initiative over a three year period. These resources – in-kind and in-cash – were allocated to the full members of the Initiative and to key partners providing support to the Catalyst network. Each of the 50 full members received funding worth more than USD 158 000 in total. This consisted of HP technology – such as tablet computers, servers and printers –valued at USD 130 000, an unrestricted cash award of USD 20 000 and approximately USD 8 000 for training, coaching and conferences. The remaining budget was allocated to the design and administration of the Catalyst Initiative, including conferences, communication and trainings. The associate members benefited from access to the Initiative network as well as from coaching and conferences, including support to attend the annual HP Catalyst summits.

This initial investment has been extended, with selected Catalyst members granted additional funds to accelerate collaboration and the success of promising, scalable STEM+ education models. The Innovation Fund, created in 2011, provided additional grants from USD 10 000 to USD 50 000 available to consortium leaders, and full and associate members on a competitive basis. In spring 2011, Innovation Fund grants were awarded to 7 partnerships of 21 organisations in total – led by 3 full members, 2 consortium leaders and 2 associate members. The Leadership Fund, created in 2012, made cash awards of USD 100 000 to selected active members, full or associate, that had already received some Catalyst funding. By the end of 2012, ten organisations had been awarded an HP Catalyst Leadership Fund grant on competitive basis. The application criteria stressed the prior success of the projects, collaborative activities and projects' ability to attract further resources and disseminate their work.

HP created a support and follow-up framework to facilitate the collaborative STEM+ education work of the Catalyst Initiative in co-operation with its long-term partner, ISTE. This included:

- *Face-to-face meetings*. The Catalyst grantees and consortium leaders were provided with opportunities for several face-to-face meetings over the course of the initiative. This included two international conferences bringing together full and associate Catalyst members, as well as more focused meetings for each consortium and opportunities for the consortium leaders to meet each other. The first meeting was held in October 2010 in Washington DC with Executive Advisors and consortium leaders to kick off the initiative. This was followed by an international conference in New Delhi, India, in March 2011 with all Catalyst members, which provided most of the original members with their first opportunity to meet face to face. The second International meeting was held in April 2012 in Beijing, China, assembling both the 2010 and 2011 cohorts. Between these two conferences, most of the six consortia held separate face-to-face meetings in late 2011 or early 2012 and there were Executive Advisors' meetings organised by HP twice a year.

- *Internal communication infrastructure*. The Initiative provided Catalyst members with the infrastructure to enable internal communication. The internal Catalyst web community, administered by ISTE, served as a space for communication, collaboration and feedback within and between the Catalyst consortia. Monthly conference calls between the consortium leaders and HP were scheduled to provide support and exchange ideas about developments within

Catalyst. HP also held monthly one-to-one discussions with each consortium leader, in addition to frequent e-mail contact.

- *Training and coaching*. Training related to collaboration and dissemination of information were organised for the Catalyst leaders and grantees in the early days of the initiative. ISTE provided coaching for the projects as required and several thematic webinars were organised. For example, the six consortia were provided with introductory webinars and a webinar on partnerships was organised at the beginning of the Initiative. The consortium leaders received turnover training, while other training was organised as necessary. Several Catalyst projects were matched with HP employees acting as HP Ambassadors who provided advice and coaching. Catalyst participants also had access to a variety of materials relevant to project planning and measurement.

- *Regular reporting and feedback*. Follow-up and monitoring of the Catalyst projects' progress were done through regular monthly "status update" surveys, which were then analysed and shared with the Catalyst members and consortium leaders. As well as brief monthly reflections, there were also more extensive annual status reports on members' progress. The consortium leaders were also surveyed with regular updates taking place a few times a year. Full members and consortium leaders were committed to reporting regularly while associate members were encourage to report but not required to.

- *Providing publicity*. The New Media Consortium (NMC) administered dedicated web pages to disseminate information about the Catalyst Initiative. This "Catalyst Hub" website was meant to serve as an aggregation portal bringing together feeds from blogs, news updates, YouTube videos, Twitter, and webinars. NMC also created and administered the Catalyst presence on Facebook. Full Catalyst members committed to disseminating their the project findings and stories through a public webpage and a video, all of which were presented in an online "gallery" hosted by NMC and visited by more than 50 000 people the month it was created. Associate members were also encouraged to disseminate information online, but this was not required.

A range of institutions who were leaders in their fields provided support for the Catalyst Initiative as Executive Advisors. These included representatives of intergovernmental organisations such as the OECD and private organisations including the Carnegie Corporation, C2k, the Consortium for School Networking, European Schoolnet, the Exploratorium, FutureLab, the Hewlett Foundation, ISTE, the National Science Resources Centre and NMC.

ANNEX G – CATALYST INITIATIVE COLLABORATION FRAMEWORK OF THE CATALYST INITIATIVE

The Catalyst Initiative was designed to promote collaboration for innovation in STEM+ education through a three-level architecture:

- *Project level.* The core research and development work was carried out through the projects run by the 50 full Catalyst member organisations worldwide. These individual projects were also expected to build collaborative partnerships and share ideas to further enhance their STEM+ education work and its impact.

- *Consortium level.* The Catalyst projects were grouped into six thematic and collaborative consortia that were expected to support the work of their individual members. The consortia were also meant to engage with educational practitioners, administrators and leaders as well as with other consortia to form a larger community of practice on a global scale. The role of the consortium leaders was to facilitate collaboration within their consortium and co-ordinate its activities as well as providing support for the projects where necessary.

- *Catalyst Initiative level.* The Catalyst Initiative itself formed a wider network of collaboration and mutual learning for the six consortia and their projects. Collaboration between and across Catalyst consortia and projects was expected to add value to the work of individual grantees and, hence, the whole grant programme. The Catalyst Initiative level was also expected to promote collaboration beyond the Catalyst network itself.

The Catalyst consortia proved diverse not only in terms of their themes, geography and size, but also in their approach to collaboration:

- *Global Collaboratory*. The Global Collaboratory consortium defined its collaborative work around a fairly traditional collaborative research plan. While this work was meant to draw largely on individual project data and achievements, the aim was also to carry out a separate survey as well as literature research for conceptual work. By late 2012, the entire Global Collaboratory consortium was preparing a collaborative book comprising case studies based on individual projects.

  Operationally, the leader made individual contact with all consortium members and a consortium workshop was also held.

- *Multi-Versity.* The Multi-Versity consortium organised its collaborative work around a structure that appeared similar to that of the overall Catalyst Initiative. Consortium members worked around four themes – serious games, online laboratories, faculty development and models for student interaction. Each included a few "area leads" from among the consortium members as well as "collaborators". The collaborators adopted and tested the thematic activities in different contexts with the support of their respective area leads. The consortium meetings "built collaboration in the development of workshop, conference presentations and collaborations" that

allowed peer feedback and sharing of resources. The next challenge was to strengthen "marketing and outreach focus".

Operationally, the consortium collaboration was supported by multiple calls, a meeting, and a series of webinars and workshops. The consortium leader saw their role as a "network gardener" who looks for "opportunities among multiversity members and between multiversity members and the outside world". Consortium members also gathered at the annual Sloan Consortium conference.

- *New Learner.* The idea of the New Learner consortium was to develop "a colloquium of academic thoughts and practices". With a view to encouraging dissemination of best practices worldwide, the consortium members were "encouraged to conduct real time teaching-learning experiments which in turn can be presented before academic circles". Many consortium members tested the universality of each other's learning models in other cultural contexts. This work was guided by a commonly sketched framework and a competency map.

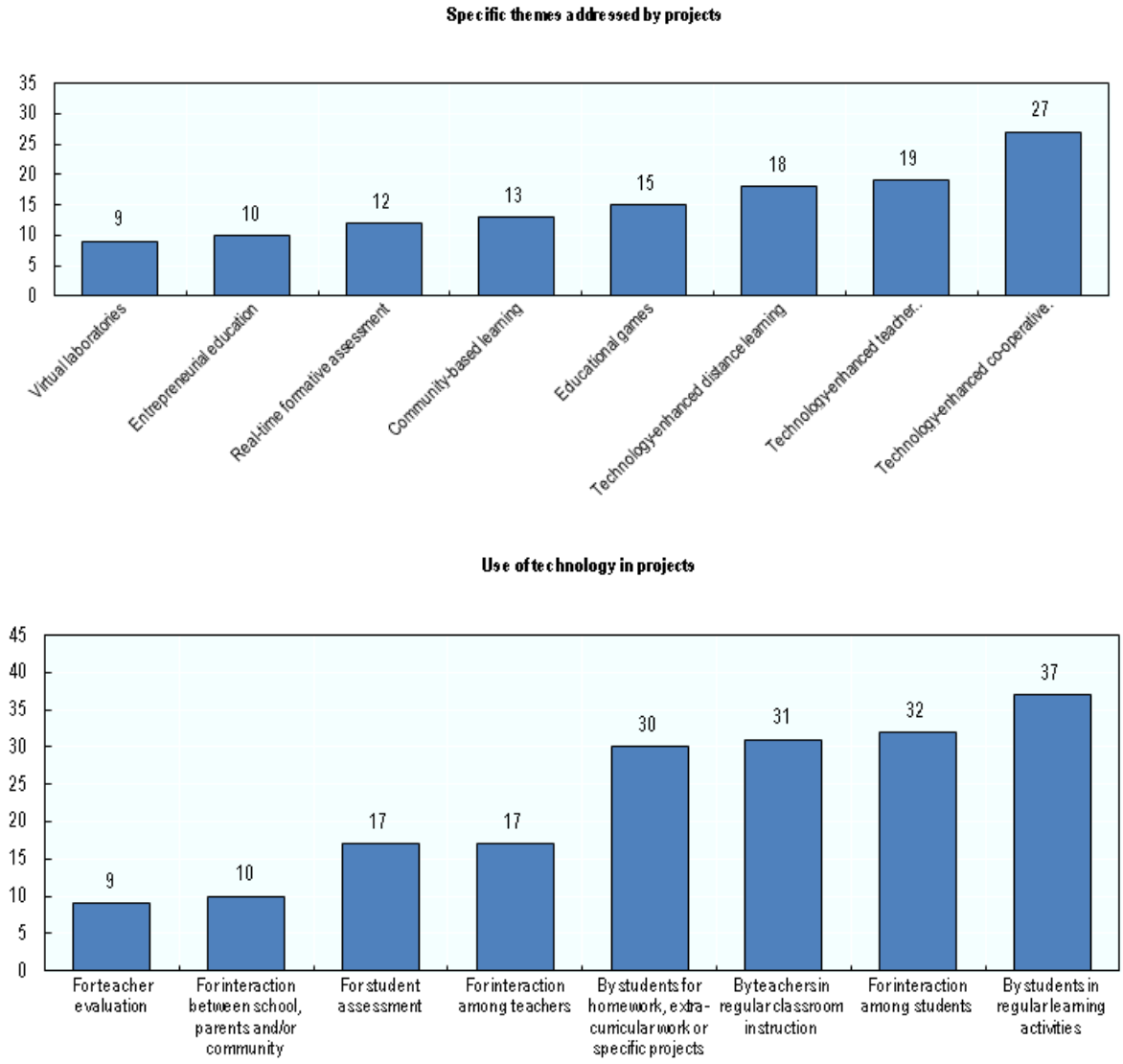
  The New Learner consortium used idea sharing and discussions as a way of advancing collaboration, in addition to the collaboration initiated by the consortium leader. The consortium established regular channels of communication, including a structured teleconferencing routine for sharing views, monthly webinars and a consortium website. The one-to-one discussions included time earmarked to discuss challenges related to the diverse contexts of the partner organisations. Since November 2011, the consortium leader has made visits to organisations on the ground, supported by an Innovation Fund grant to further enhance collaboration and initiate collaborative activities. The leader saw their role as a "facilitator", "initiator", "match maker" and "critical friend" for dialogue, assistance and collaboration between consortium members.

- *Pedagogy 3.0*. The Pedagogy 3.0 consortium relied on a participatory process to define its work. A few consortium members took the lead in defining the concept of "Pedagogy 3.0", which was discussed with the other consortium members.

- Operationally, the Pedagogy 3.0 consortium held quarterly meetings and monthly events to enhance the development of ideas and mutual understanding within the consortium. A face-to-face meeting was held in November 2011. The consortium leader conducted several weekly one-to-one meetings with individual grantees to build relationships. Although actively building collaboration among the members, the leader saw their role evolving towards being a "broker" for collaboration within the consortium and "bridger" across the other consortia.

ANNEX H – TECHNOLOGY USED WITHIN THE CATALYST INITIATIVE

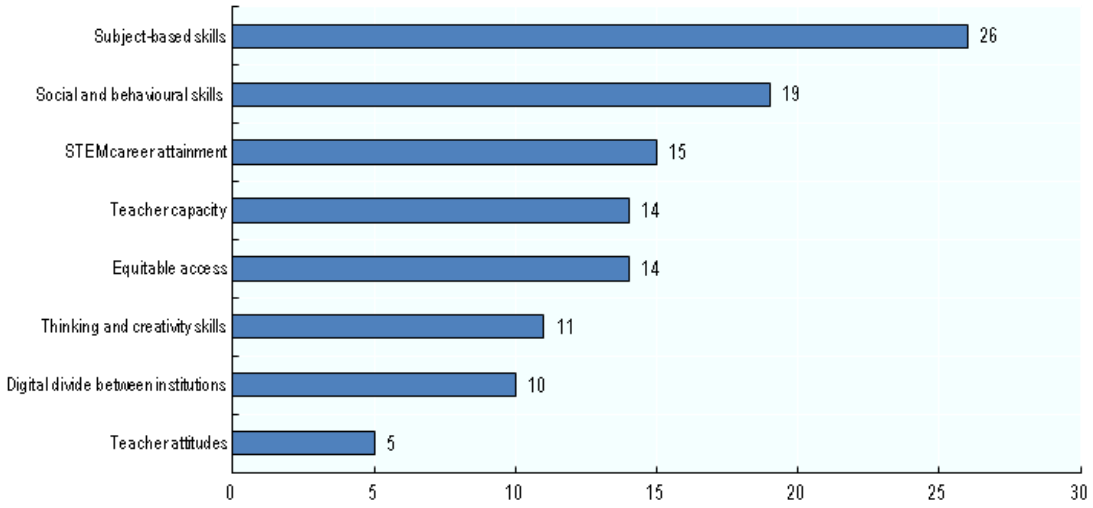
Figure H.1. Specific themes and technology used by the Catalyst projects (46 projects)



Source: HP Catalyst Final and First Year Reports (2012).

ANNEX I – EDUCATIONAL OBJECTIVES OF THE CATALYST PROJECT WORK

Figure I.1. Overview of the educational objectives of the Catalyst projects (48 projects)



Note: Coded from the narrative data. Individual projects may have several educational objectives at the same time.

Source: HP Catalyst Baseline Questionnaires (2011).

In line with the overall goals of the Catalyst Initiative, the projects aimed to improve a variety of educational outcomes (Chart I.1):

- *Student skills and STEM career attainment.* Improving student skills and increasing their STEM career attainments were important objectives for the Catalyst Projects. Two-thirds of the projects sought to increase skills of some sort, especially subject-based know-how. More than half aimed to improve students' achievement in and understanding of STEM topics, concepts and methodologies. More than one-third aspired to enhance social and behavioural competences. This often meant increasing students' interest in STEM subjects, but also improving skills such as collaboration and communication. Roughly one-fifth of the projects targeted skills such as creativity, critical thinking, innovation and problem-solving. Nearly one-third of them sought to advance the recruitment, retention and engagement of students in STEM-related fields.

- *Equitable access to education.* Promoting more equitable access to STEM+ education also emerged as a significant objective for many of the 50 projects. Overall, more than one-third of the projects aimed to improve access to STEM education either for students or institutions. More than one-quarter aimed to enhance student access through improving remote education, providing a wider range of learning opportunities and expanding opportunities for technology-based education. A fifth of projects sought to bridge the digital divide between educational institutions.

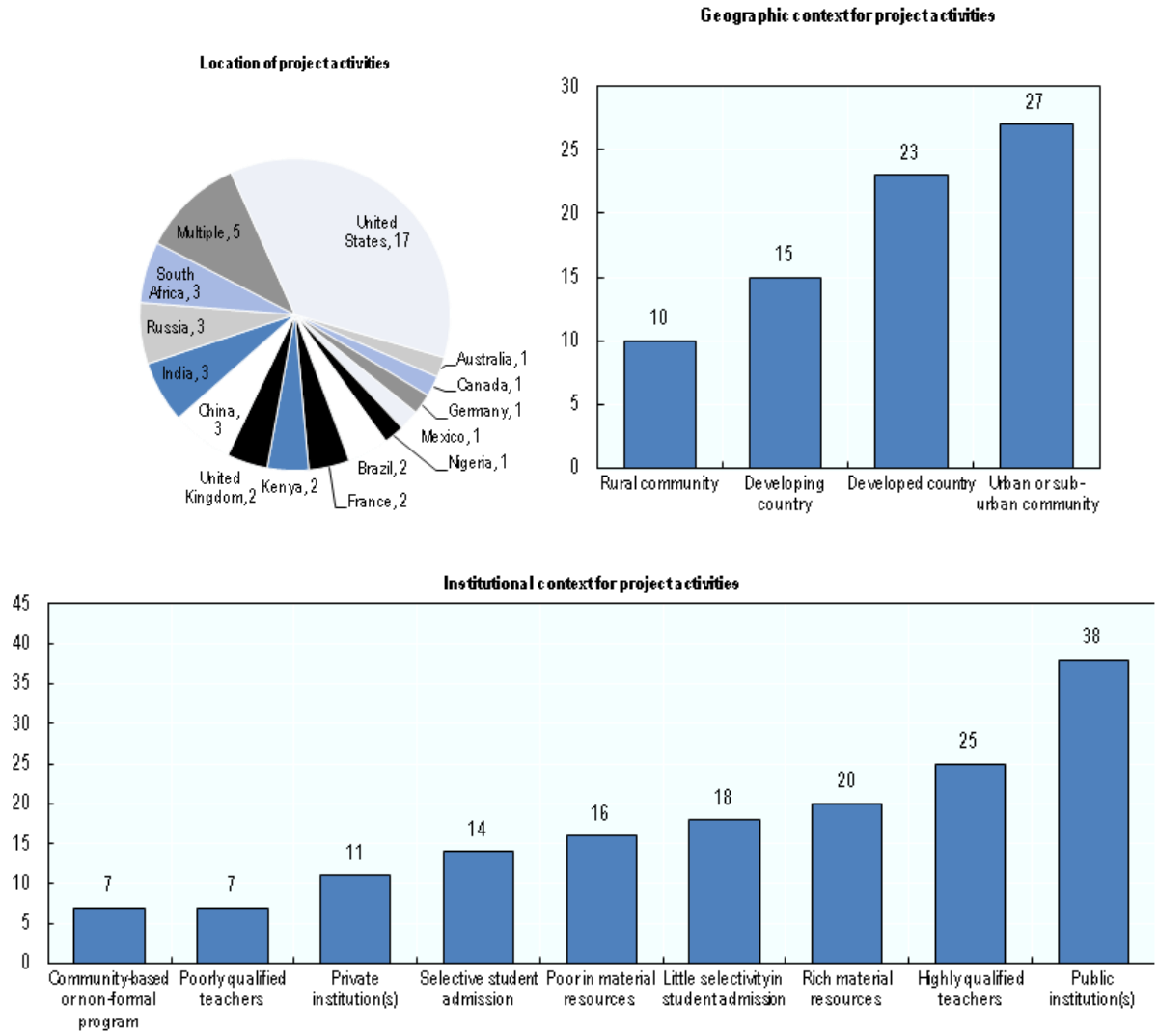
- *Teacher capacity and attitudes.* Many Catalyst projects aimed to enhance teacher capacity and, to a lesser extent, attitudes. More than one-quarter of the projects sought to improve teachers' skills,

including their capacity to use technology. Many projects focused on improving teachers' STEM and pedagogical know-how, self-efficacy or planning and development skills. Some projects aimed to promote better teacher attitudes and engagement especially regarding the use of technology in education.

Most of the individual Catalyst projects got inspiration from education-related opportunities and challenges, while addressing some wider economic and social needs could also act as a driver. Three-quarters of the projects took advantage of opportunities to enhance education quality through student-centred, interdisciplinary or technology-enabled learning. Some projects drew on ideas such as collaboration or networks for teacher capacity building or sought to grasp possibilities brought by new technologies to enhance access to education. At the same time, nearly half addressed STEM+ education quality challenges. A few focused on equitable access to education or implementation of educational innovations. Addressing wider economic and social challenges explicitly drove one-third of the projects while one-quarter aimed to meet labour market needs and some addressed STEM career or citizenship needs. Most Catalyst members built their interventions on their past work and expertise.

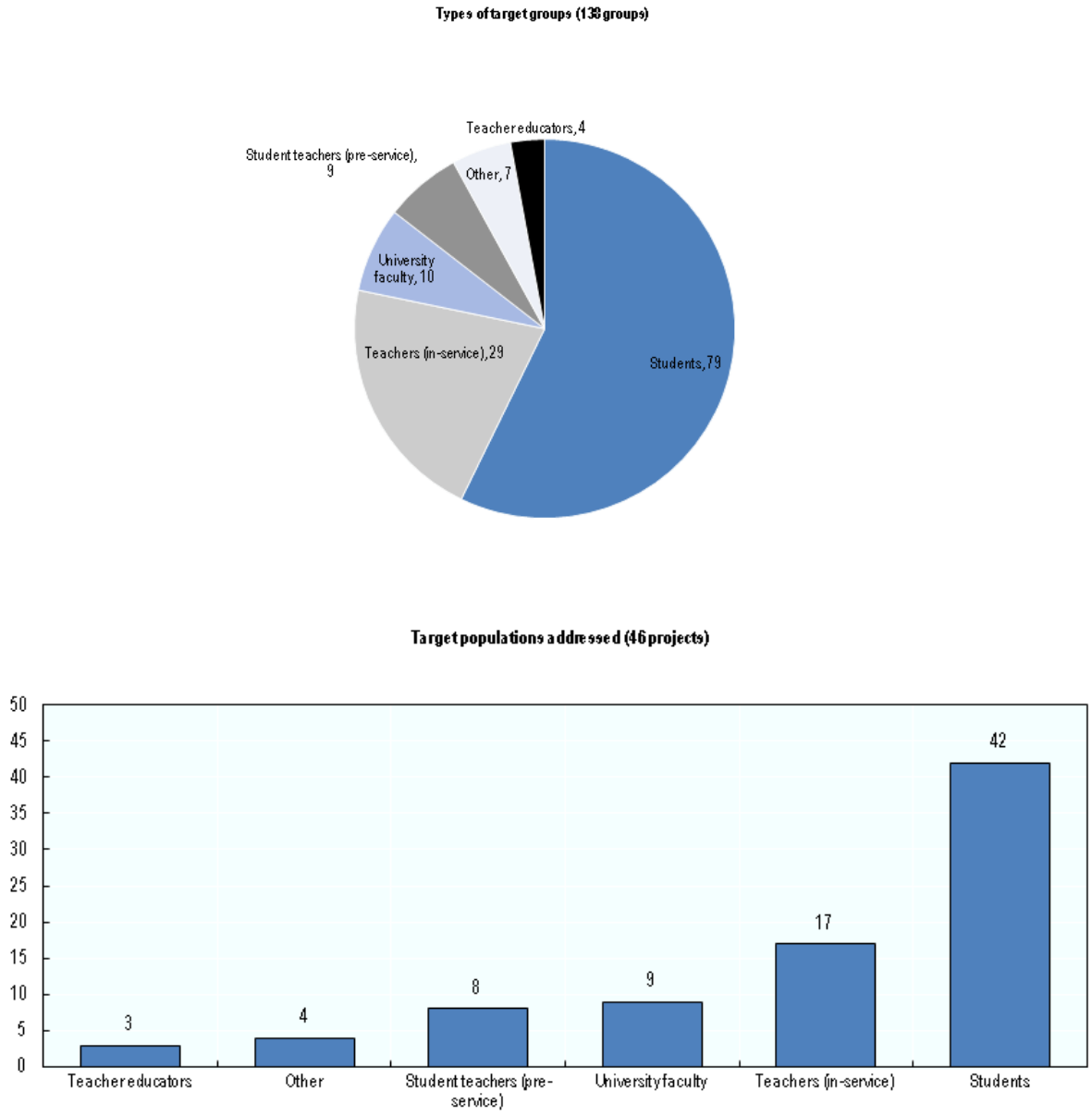
ANNEX J – CONTEXT AND TARGET GROUPS OF THE CATALYST INITIATIVE

Figure J.1. Catalyst projects: Context (46 projects)



Source: HP Catalyst Final and First Year Reports (2012).

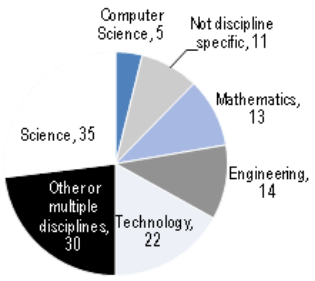
Figure J.2. Catalyst projects: Target groups



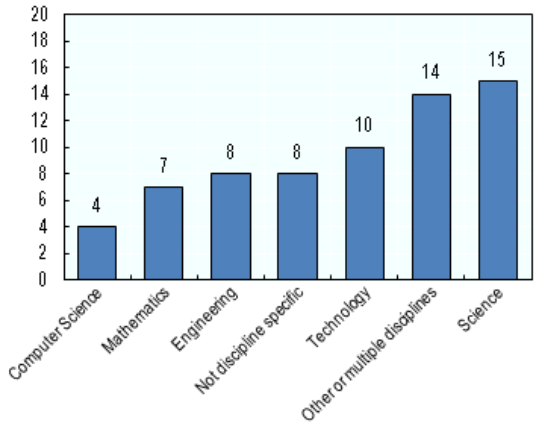
Source: HP Catalyst Final and First Year Reports (2012).

Figure J.3. Catalyst projects: Subjects

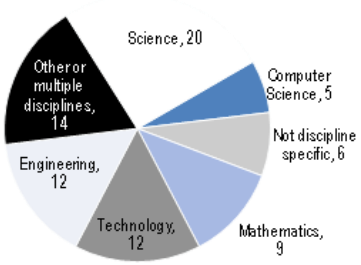
All target groups by subject (130 groups)



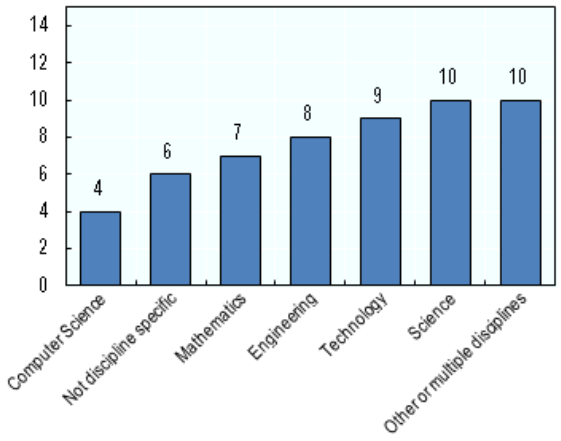
All target groups by subject (46 projects)



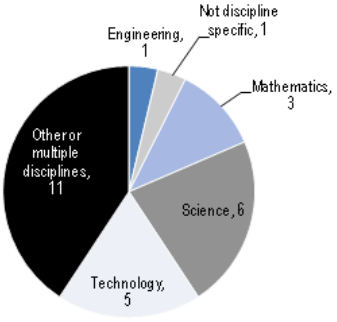
Student target groups by subject (78 groups)



Student target groups by subject (42 projects)



In-service teacher target groups by subject (27 groups)



In-service teacher target groups by subject (17 projects)

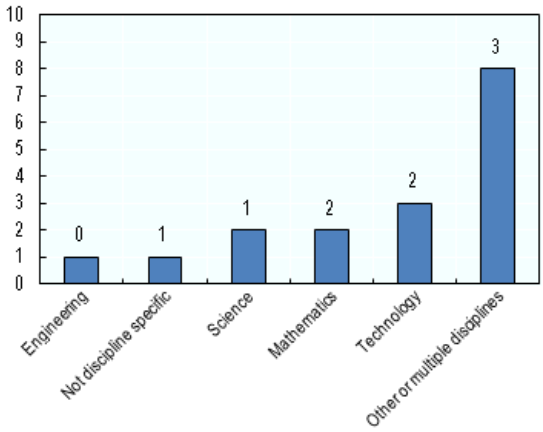


Figure J.4. Catalyst Projects: Education levels

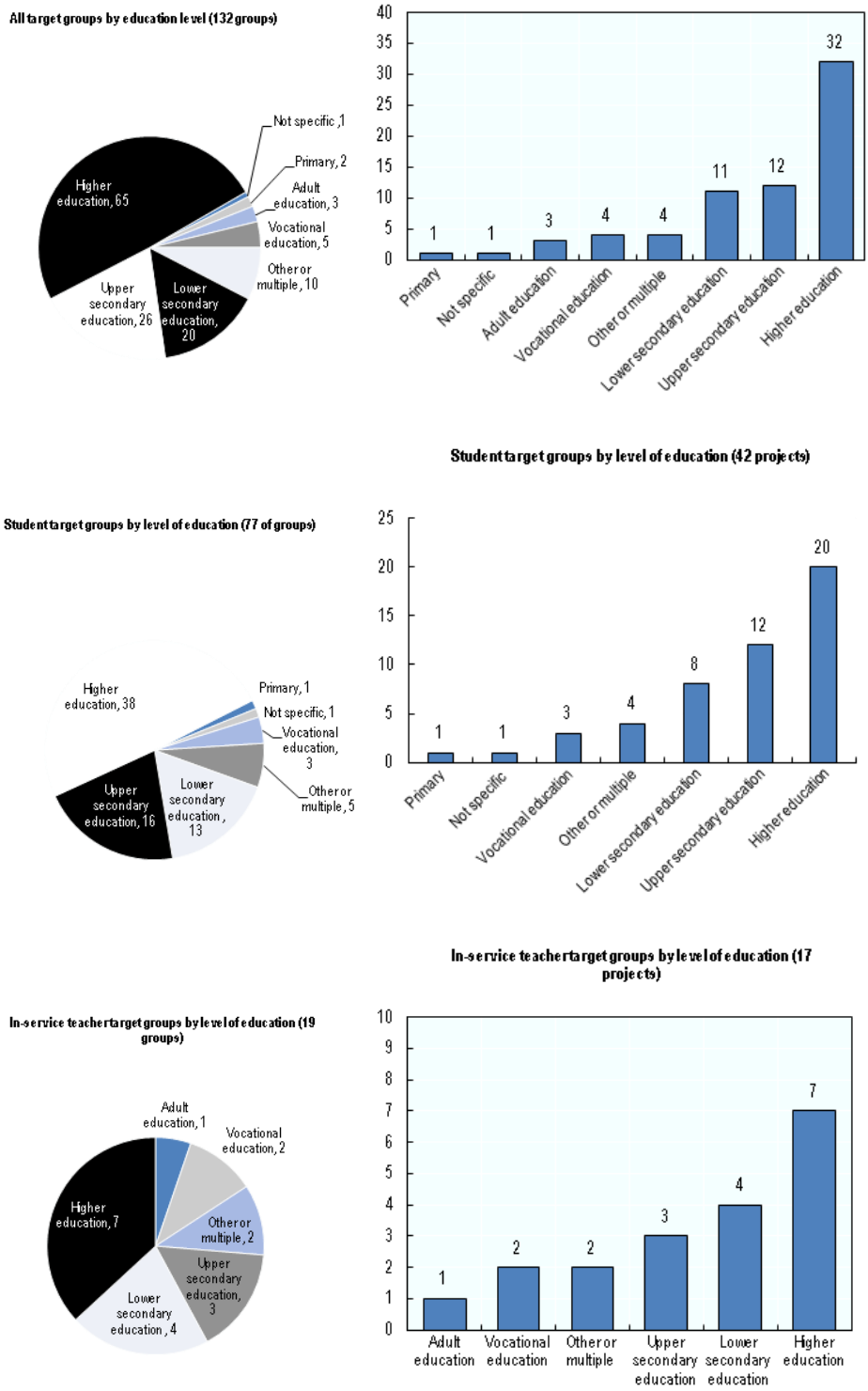
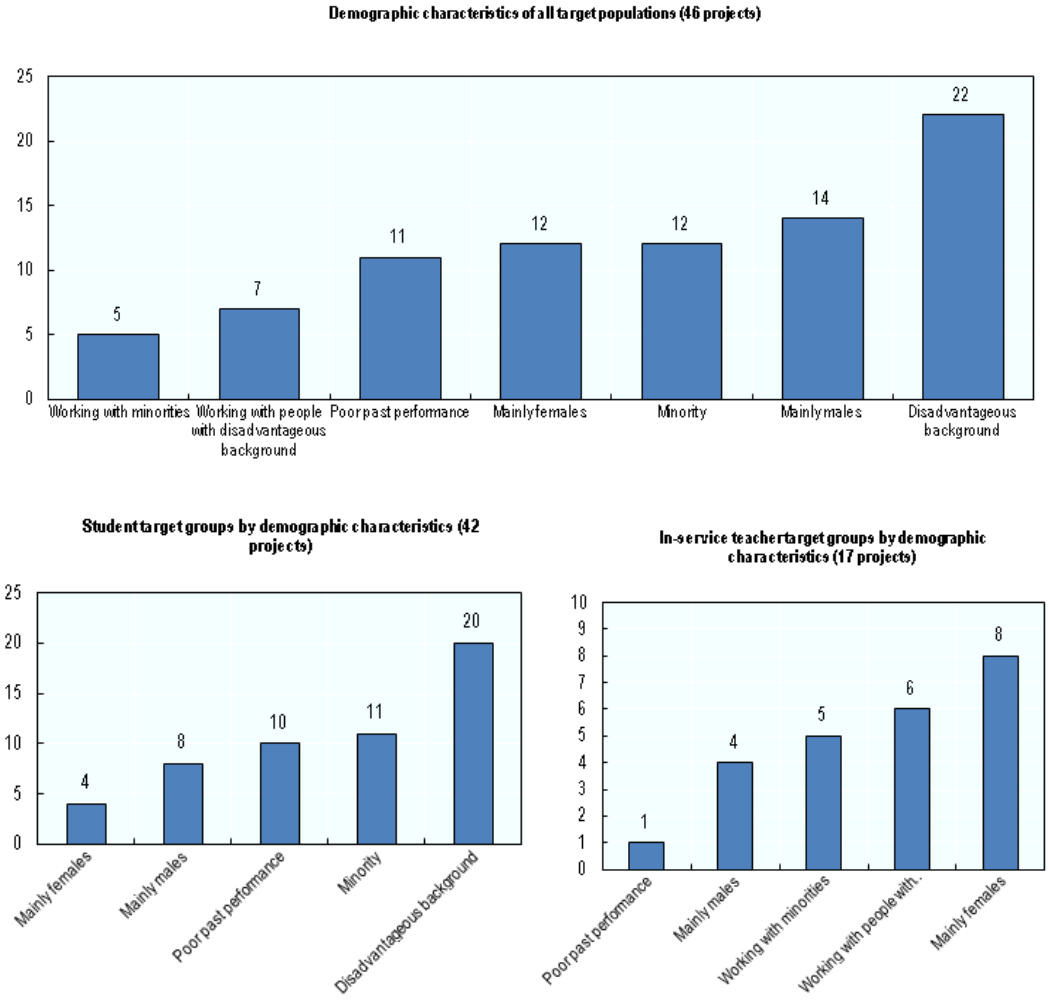
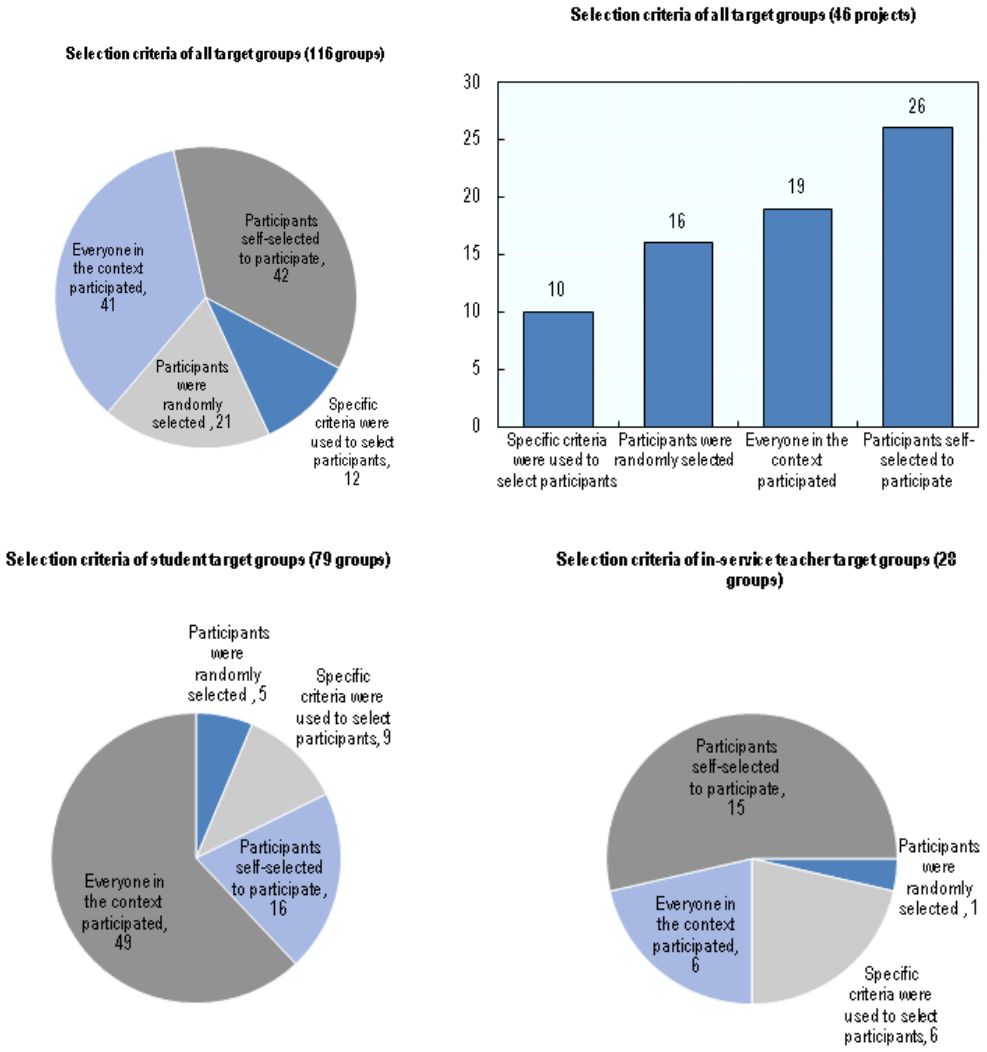


Figure J.5. Catalyst projects: Target population demographics



Source: HP Catalyst Final and First Year Reports (2012).

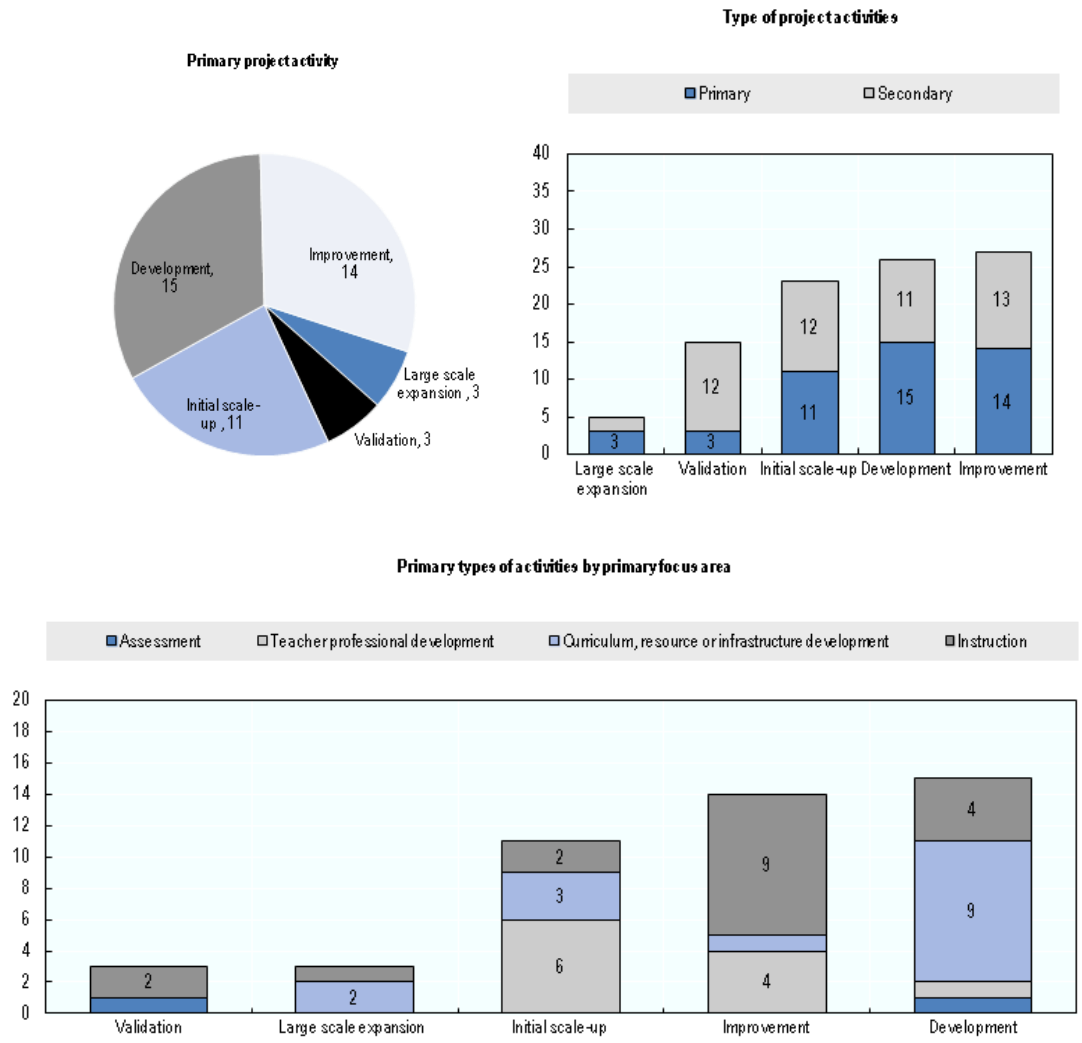
Figure J.6. Catalyst projects: Group selection



Source: HP Catalyst Final and First Year Reports (2012).

ANNEX K – TYPE OF CATALYST PROJECT WORK

Figure K.1. Catalyst projects: Types of activity (46 projects)



Note: The closed-question data was corrected for some projects based on the narrative report.

Source: HP Catalyst Final and First Year Reports (2012).

ANNEX L – OUTCOMES FROM THE CATALYST PROJECT WORK

Figure L.1. Catalyst projects: Development outcomes (42 projects)

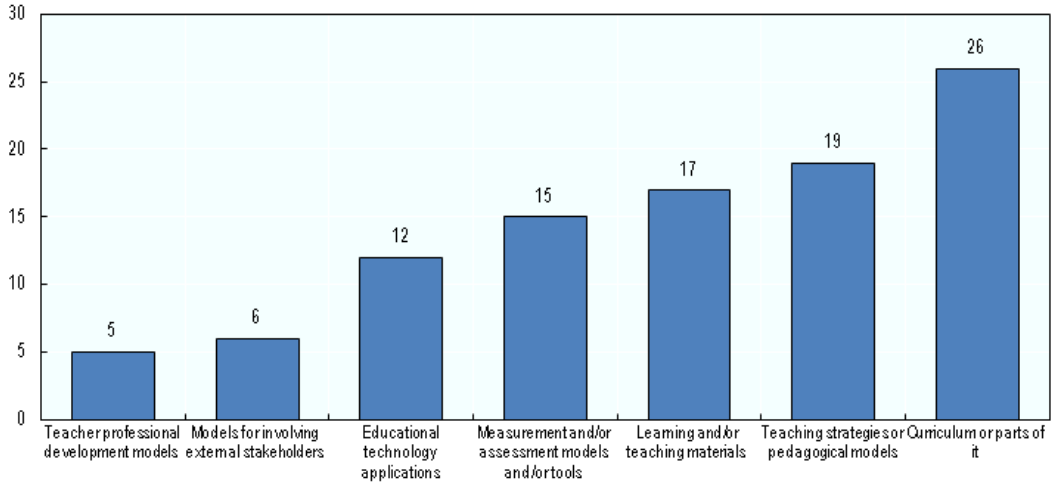
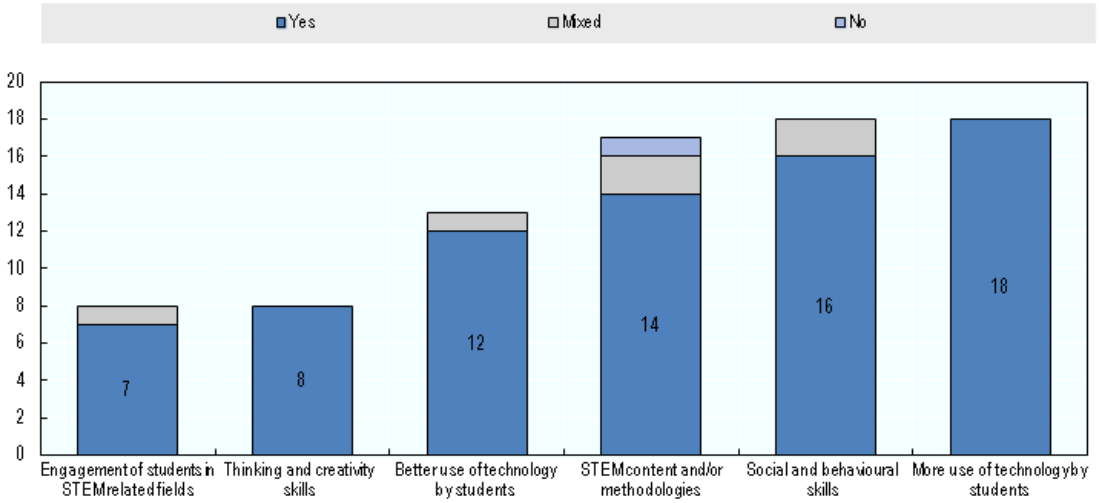


Figure L.2. Catalyst projects: Learning and behavioral outcomes (42 projects)



Note: The closed-question data was corrected based on sufficient quantitative and qualitative evidence provided in the narrative report.

Source: HP Catalyst Final and First Year Reports (2012).

Figure L.3. Catalysts Projects: Teacher outcomes (42 projects)

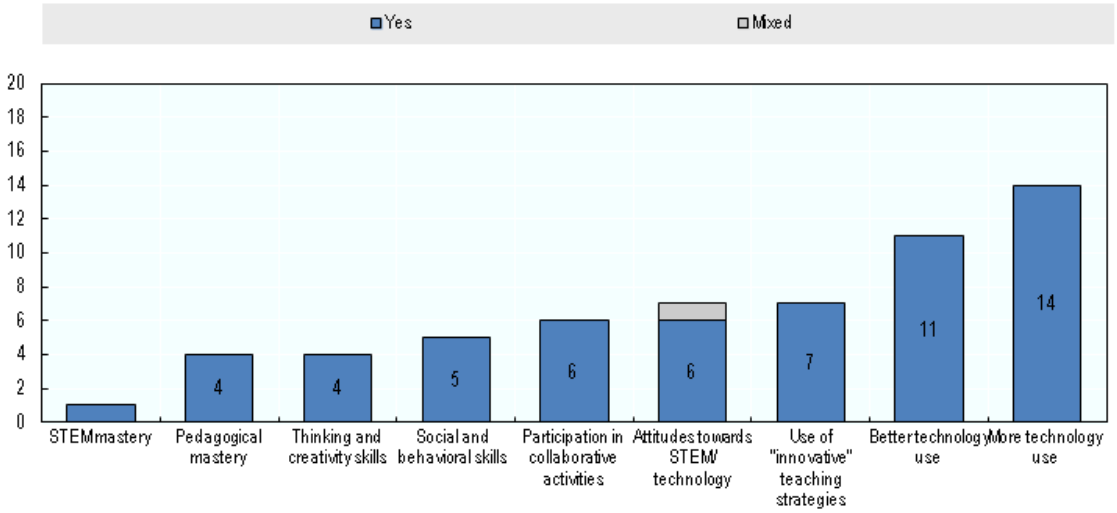
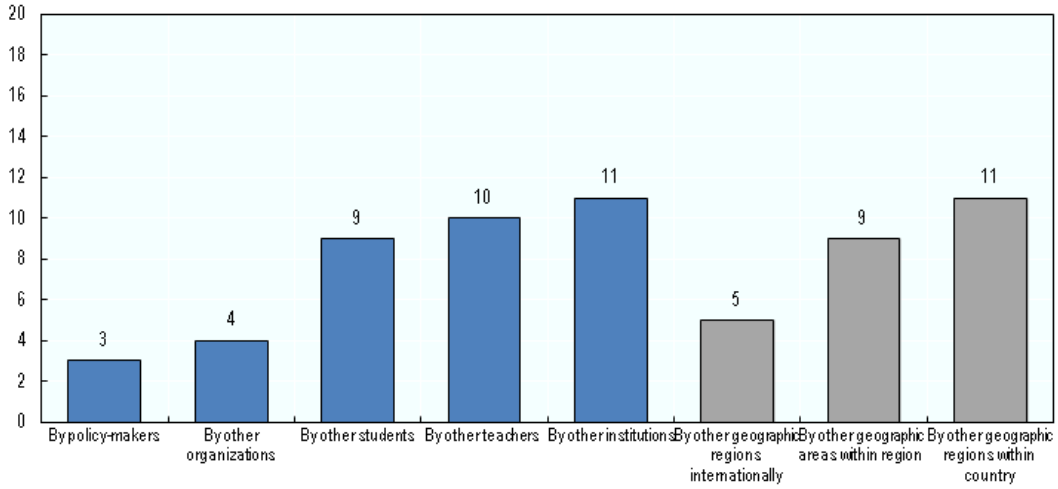


Figure L.4. Catalyst projects: Diffusion and adoption outcomes (42 projects)

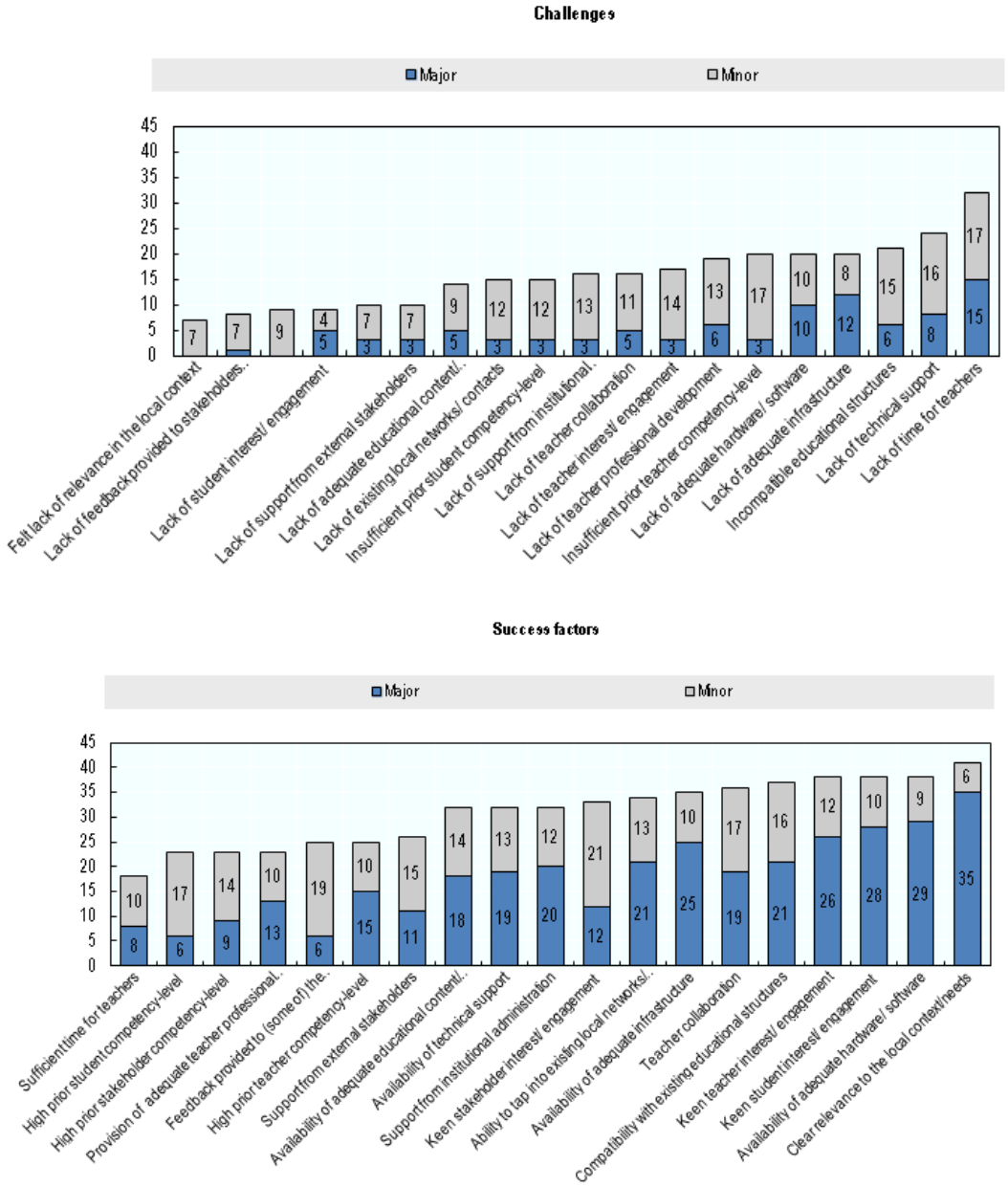


Note: The closed-question data was corrected based on sufficient quantitative and qualitative evidence provided in the narrative report.

Source: HP Catalyst Final and First Year Reports (2012).

ANNEX M – SCALABILITY CONSIDERATIONS FOR THE CATALYST PROJECT

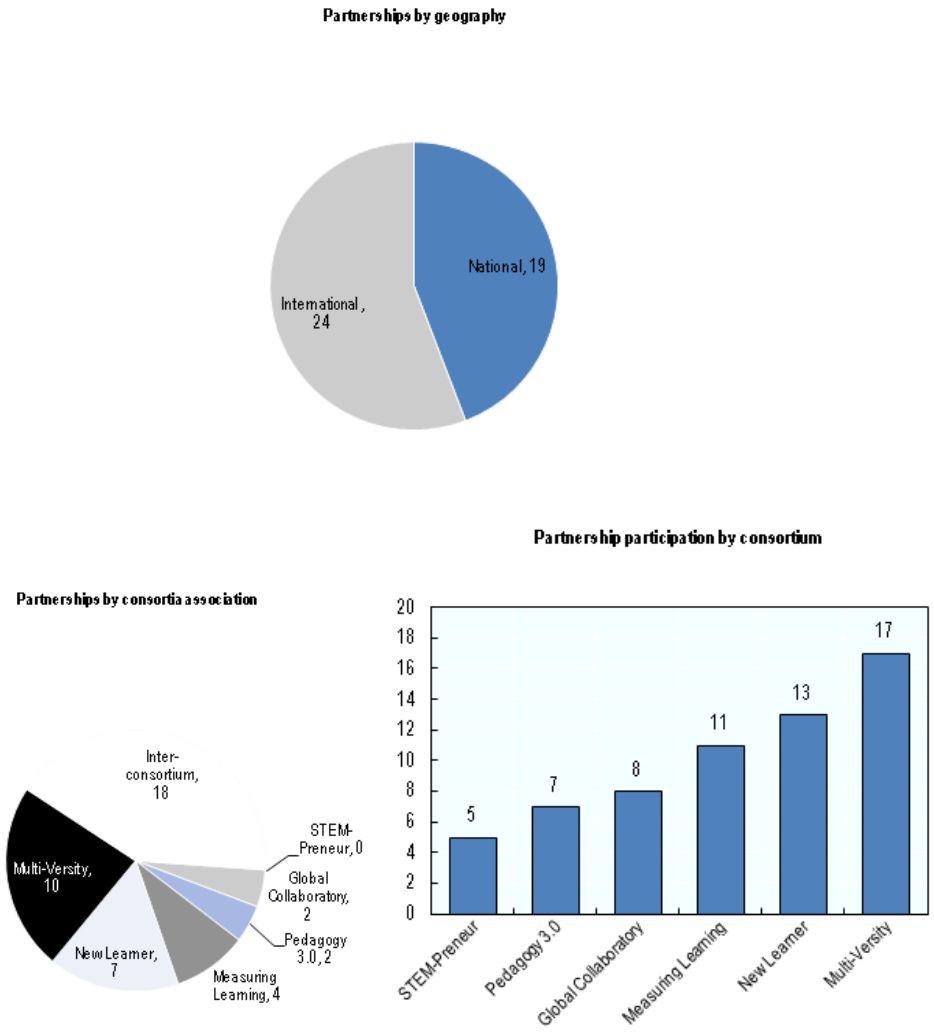
Figure M.1. Catalyst projects: considerations for scaling up (46 projects)



Source: HP Catalyst Final and First Year Reports (2012).

ANNEX N – CATALYST COLLABORATIONS BY GEOGRAPHY AND CONSORTIA

Figure N.1. Catalyst partnerships by geography and consortium (43 partnerships)



Source: HP Catalyst Final and First Year Reports (2012).

Table N.1. Partnerships within consortia since the start of the Catalyst Initiative

International	
Agastya Foundation (Lead NL, 2010, India) and Longwood University (Full NL, 2010, the United States)	Educational tools/methods - Teacher professional development - Framework/ concept/ methodology development - Research/ publications - Meetings/ networking support - Awareness raising/ dissemination - Diffusion/ adoption support
Agastya Foundation (Lead NL, 2010, India) and Reach the World (Full NL, 2010, the United States)	Implementation/ testing - Educational tools/methods - Teacher professional development - Conceptual/ methodological support - Framework/ concept/ methodology development - Awareness raising/ dissemination
Agastya Foundation (Lead NL, 2010, India) and City Academy Norwich (Full NL, 2011, the United Kingdom)	Implementation/ testing
Amrita University (Full ML, 2011, India) and Colorado School of Mines (Full ML, 2010, the United States)	Implementation/ testing - Data
Cairo University (Full CG, 2010, Egypt) and East Carolina University (Full CG, 2010, the United States)	Conceptual/ methodological support - Educational content - Educational tools/methods - Awareness raising/ dissemination
City Academy Norwich (Full NL, 2011, the United Kingdom) and St. Thomas Aquinas College (Full NL, 2011, the United States)	Implementation/ testing
City Academy Norwich (Full NL, 2011, the United Kingdom) and University of Fort Hare (Full NL, 2010, South Africa)	Implementation/ testing
East Carolina University (Full CG, 2010, the United States) and Strathmore University (Associate CG, 2010, Kenya)	Educational content
FISK University (Full MV, 2011, the United States) and Thompson Rivers University (Full MV, 2011, Canada)	Educational tools/methods
Kenyatta University (Full P3, 2010, Kenya) and University of Bristol (Full P3, 2010, the United Kingdom)	Educational tools/methods - Educational content - Teacher professional development
Longwood University (Full NL, 2010, the United States) and University of Fort Hare (Full NL, 2010, South Africa)	Implementation/ testing - Teacher professional development - Research/ publications - Meetings/ networking support
Pontifical Catholic University of Rio de Janeiro (Full MV, 2010, Brazil) and State University of New York (Full MV, 2010, the United States)	Conceptual/ methodological support
State University of New York (Full MV, 2010, the United States) and University of KwaZulu-Natal (Associate MV, 2010, South Africa)	Conceptual/ methodological support
Universidad de las Américas Puebla (Full ML, 2011, Mexico) and University of Science and Arts of Oklahoma (Associate ML, 2010, the United States)	Framework/ concept/ methodology development - Research/ publications - Educational content - Educational tools/methods - Awareness raising/ dissemination - Diffusion/ adoption support
University of Bristol (Full P3, 2010, the United Kingdom) and University of Exteter (Full P3, 2010, the United Kingdom)	Framework/ concept/ methodology development
PLANNED - Center for Digital Inclusion (Full NL, 2011, Brazil) and Reach the World (Full NL, 2010, the United States)	Implementation/ testing - Teacher professional development - Conceptual/ methodological support - Framework/ concept/ methodology development - Awareness raising/ dissemination - Diffusion/ adoption support
National	
Colorado School of Mines (Full ML, 2010, the United States) and Rancocas Valley Regional High School (Full ML, 2010, the United States)	Implementation/ testing - Educational tools/methods - Framework/ concept/ methodology development - Awareness raising/ dissemination - Diffusion/ adoption support
National University (Full MV, 2010, the United States) and West Chester University (Associate MV, 2010, the United States)	Framework/ concept/ methodology development - Research/ publications - Awareness raising/ dissemination - Diffusion/ adoption support
Sloan-Consortium (Lead MV, 2010, the United States) and State University of New York (Full MV, 2010, the United States)	Research/ publications - Teacher professional development - Awareness raising/ dissemination - Diffusion/ adoption support
State University of New York (Full MV, 2010, the United States) and West Chester University (Associate MV, 2010, the United States)	Educational content
PLANNED - FISK University (Full MV, 2011, the United States) and State University of New York (Full MV, 2010, the United States)	Research/ publications

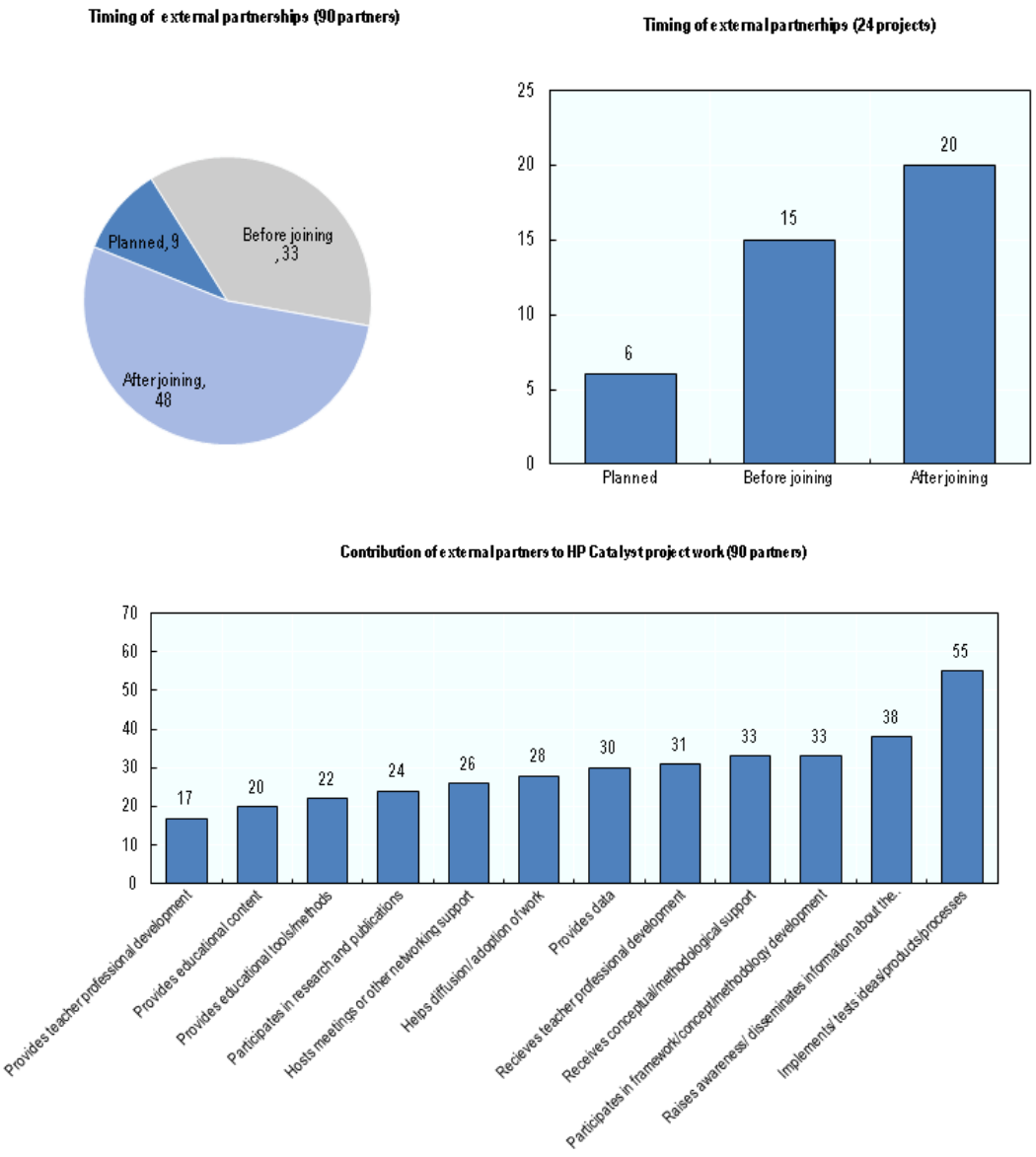
Table N.2. Cross-consortium partnerships since the start of the Catalyst Initiative

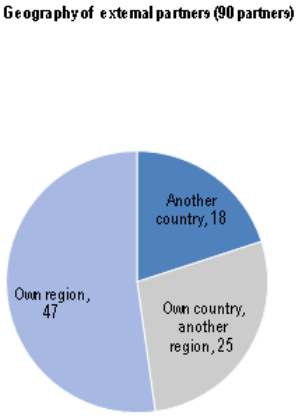
International	
Carnegie Mellon University (Lead ML, 2010, the United States) and EMLYON Business School (Full SP, 2011, France)	Implementation/ testing - Educational tools/methods
China University of Geosciences (Associate GC, 2010, China) and National Research Irkutsk State Technical University (Full ML, 2010, Russia)	Conceptual/ methodological support - Framework/ concept/ methodology development
City Academy Norwich (Full NL, 2011, the United Kingdom) and West Chester University (Associate MV, 2011, the United States)	Framework/ concept/ methodology development - Awareness raising/ dissemination
City Academy Norwich (Full NL, 2011, the United Kingdom) and Stellenbosch University (Associate MV, 2010, South Africa)	Implementation/ testing
City Academy Norwich (Full NL, 2011, the United Kingdom) and Learning Games Network (Full P3, 2010, the United States)	Implementation/ testing
PLANNED - Conestoga College (Full SP, 2011, Canada) and State University of New York (Full MV, 2010, the United States)	Implementation/ testing - Educational tools/methods - Framework/ concept/ methodology development - Awareness raising/ dissemination - Diffusion/ adoption support
PLANNED - University of KwaZulu-Natal (Associate MV, 2010, South Africa) and Conestoga College (Full SP, 2011, Canada)	Implementation/ testing - Teacher professional development - Framework/ concept/ methodology development - Awareness raising/ dissemination - Diffusion/ adoption support
National	
Agastya Foundation (Lead NL, 2010, India) and Amrita University (Full ML, 2011, India)	Implementation/ testing - Awareness raising/ dissemination - Diffusion/ adoption support
California State University Northridge (Full P3, 2010, the United States) and Colorado School of Mines (Full ML, 2010, the United States)	Research/ publications - Data - Educational tools/methods
City Academy Norwich (Full NL, 2011, the United Kingdom) and Coventry University (Full CG, 2010, the United Kingdom)	Awareness raising/ dissemination - Diffusion/ adoption support
Colorado School of Mines (Full ML, 2010, the United States) and State University of New York (Full 2010, MV, the United States)	Educational content
East Carolina University (Full GC, 2010, the United States) and State University of New York (Full 2010, MV, the United States)	Meetings/ networking support
Ecole Centrale de Lyon (Full ML, 2010, France) and EMLYON Business School (Full SP, 2011, France)	Implementation/ testing - Educational content - Educational tools/methods - Teacher professional development - Conceptual/ methodological support - Framework/ concept/ methodology development - Research/ publications - Data - Meetings/ networking support - Awareness raising/ dissemination
Longwood University (Full NL, 2010, the United States) and Northern Arizona University (Associate P3, 2010, the United States)	Framework/ concept/ methodology development - Research/ publications - Awareness raising/ dissemination - Diffusion/ adoption support
Northern Arizona University (Associate P3, 2010, the United States) and Stamford Public Schools (Full GC, 2010, the United States)	Teacher professional development
PLANNED - Masinde Muliro University (Full GC, 2010, Kenya) and Kenyatta University (Full P3, 2010, Kenya)	Teacher professional development

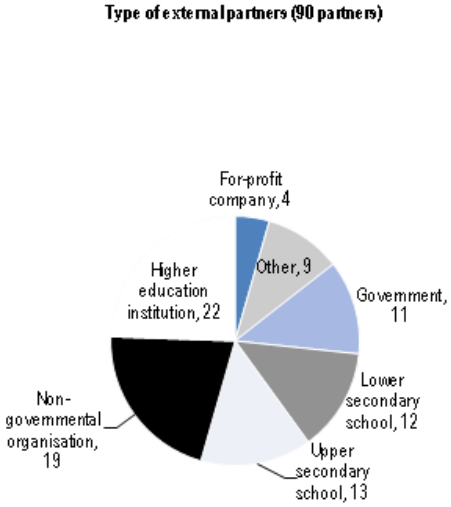
Source: HP Catalyst Final and First Year Reports (2012).

ANNEX O – CATALYST INITIATITVE EXTERNAL NETWORK

Figure O.1. Catalyst members: External partners



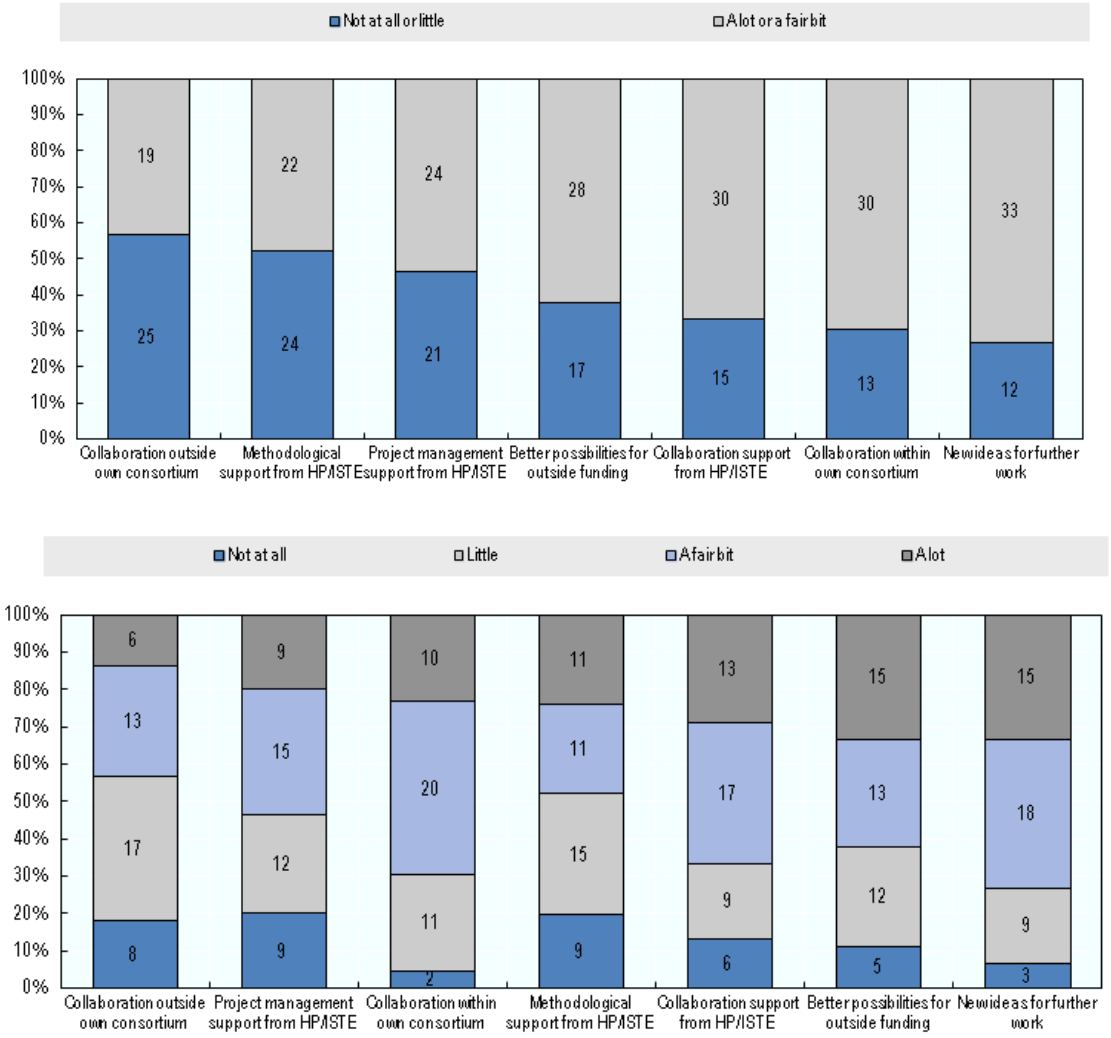




Source: HP Catalyst Final and First Year Reports (2012).

ANNEX P – NON-FINANCIAL BENEFITS OF THE CATALYST INITIATIVE

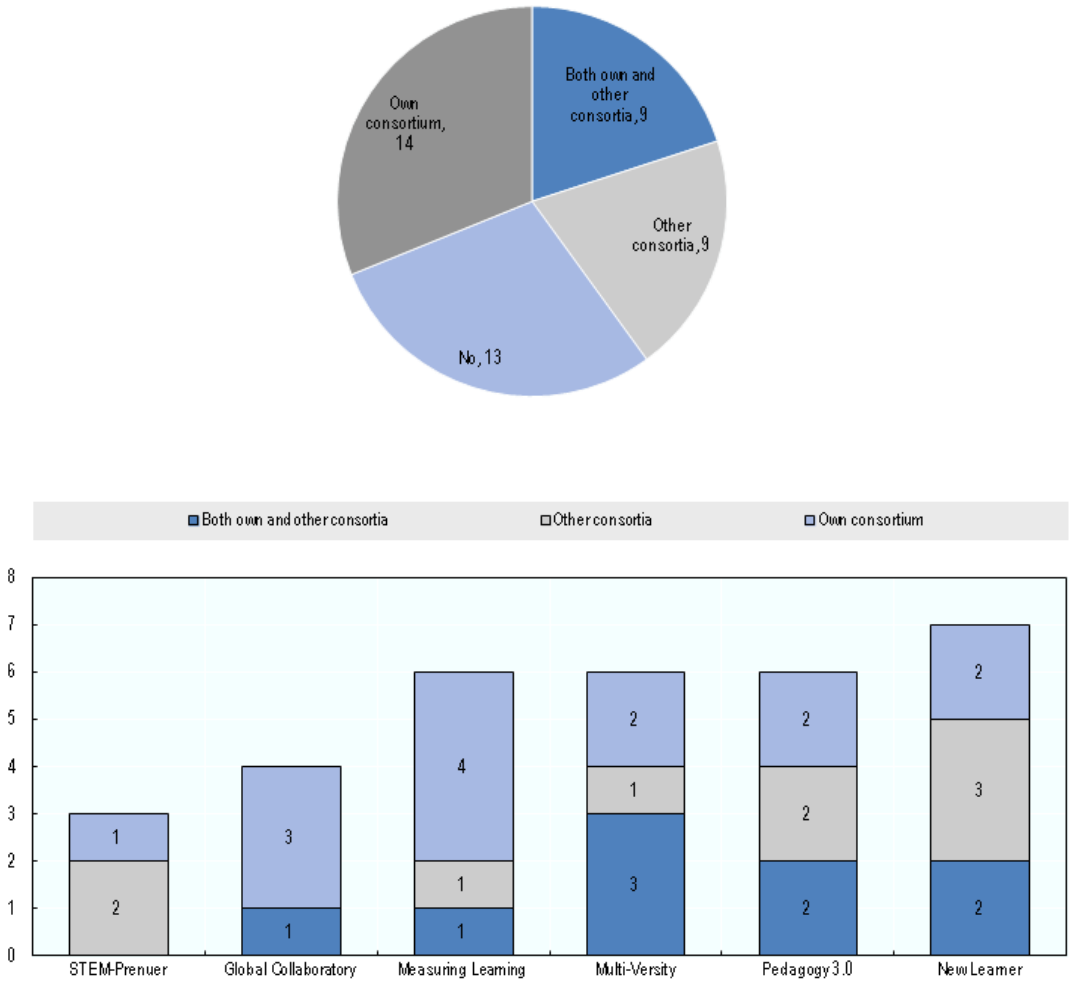
Figure P.1. Perceived non-financial benefits from Catalyst Initiative participation (46 projects)



Source: HP Catalyst Final and First Year Reports (2012).

ANNEX Q – COLLABORATION BENEFITS BY CATALYST CONSORTIA

Figure Q.1. New ideas resulting from different Catalyst collaboration or exchanges (45 projects)



Source: HP Catalyst Final and First Year Reports (2012).

Figure Q.2. Perceived benefits of collaboration by consortium

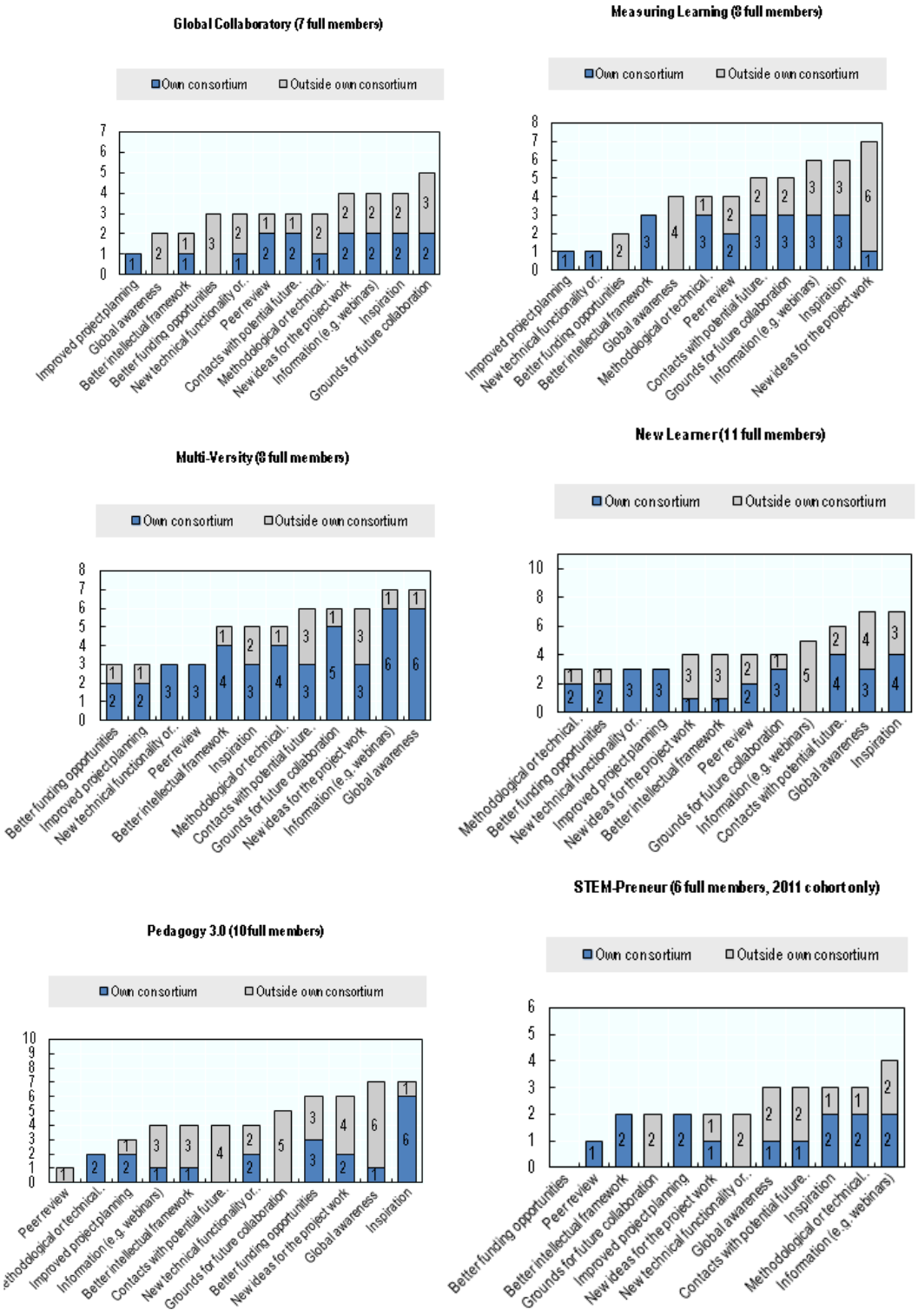
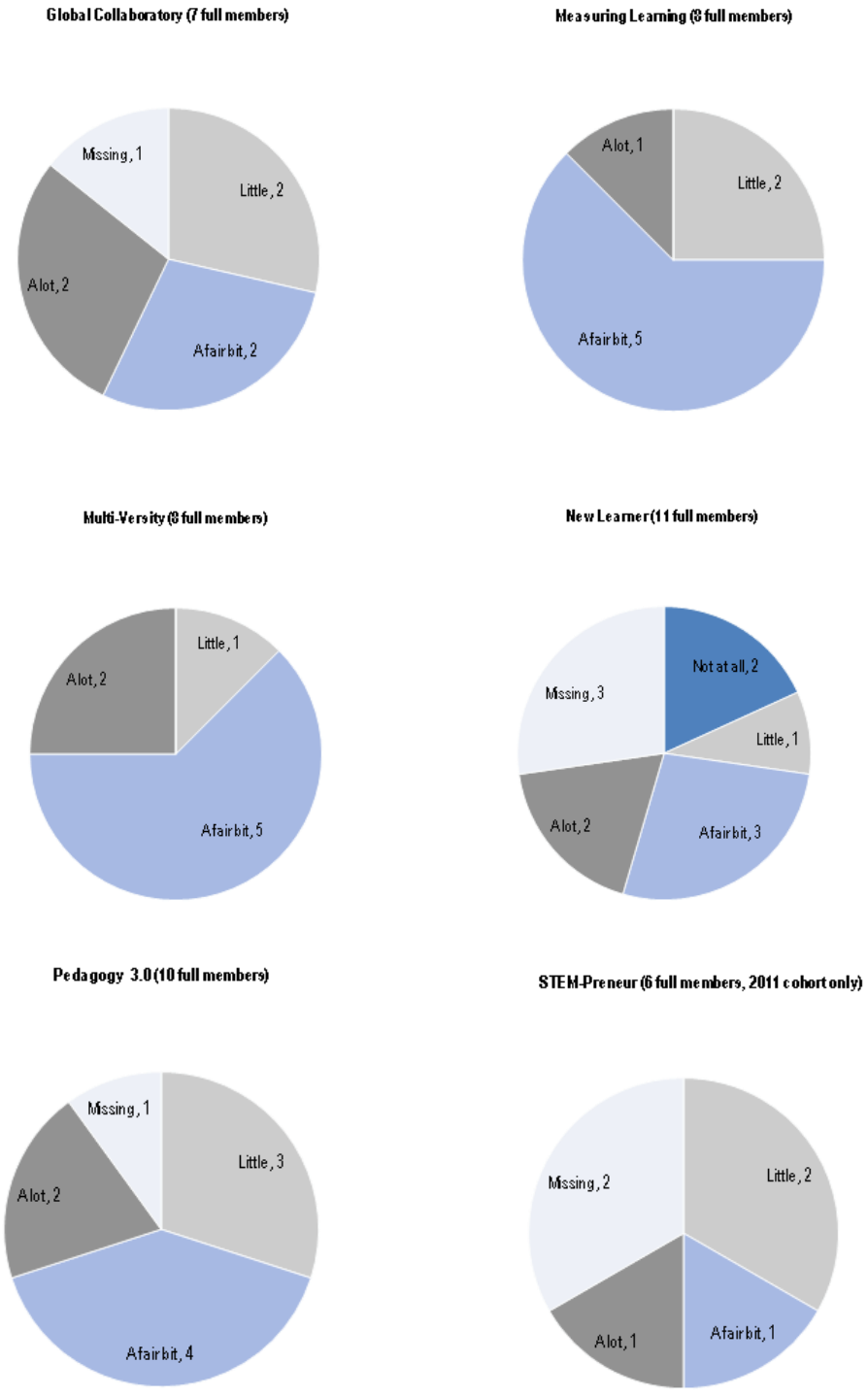
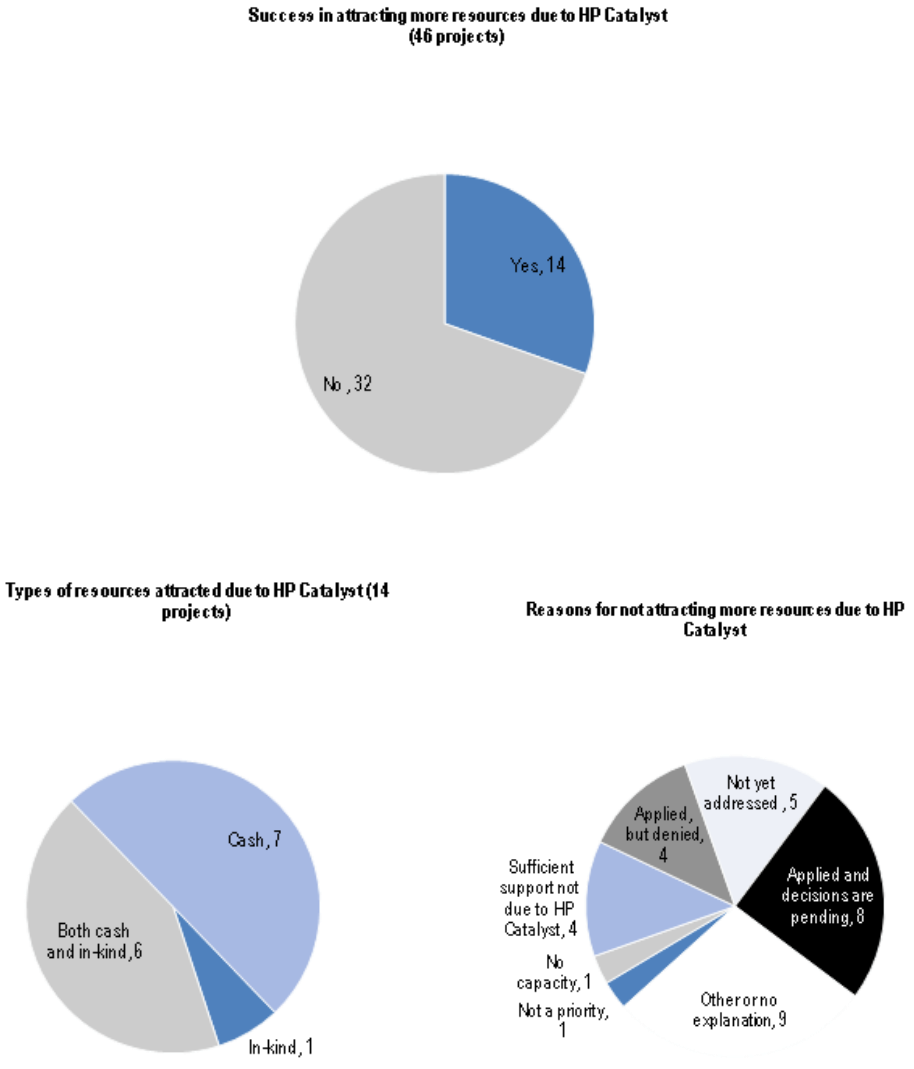


Figure Q.3. Extent of benefits from collaboration by consortium



ANNEX R – ATTRACTING FURTHER RESOURCES THROUGH CATALYST INVOLVEMENT

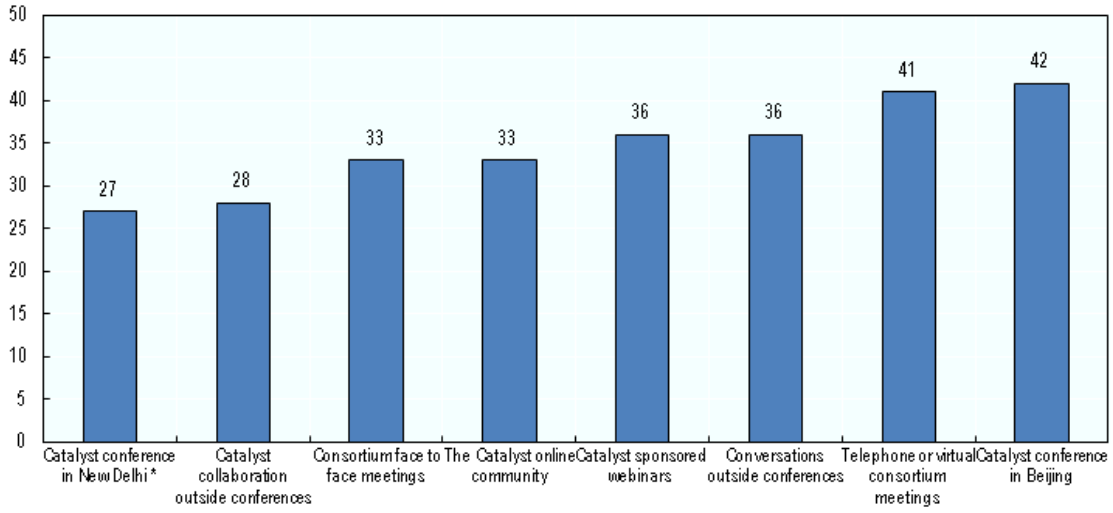
Figure R.1. Success in attracting further resources through Catalyst involvement



Source: HP Catalyst Final and First Year Reports (2012).

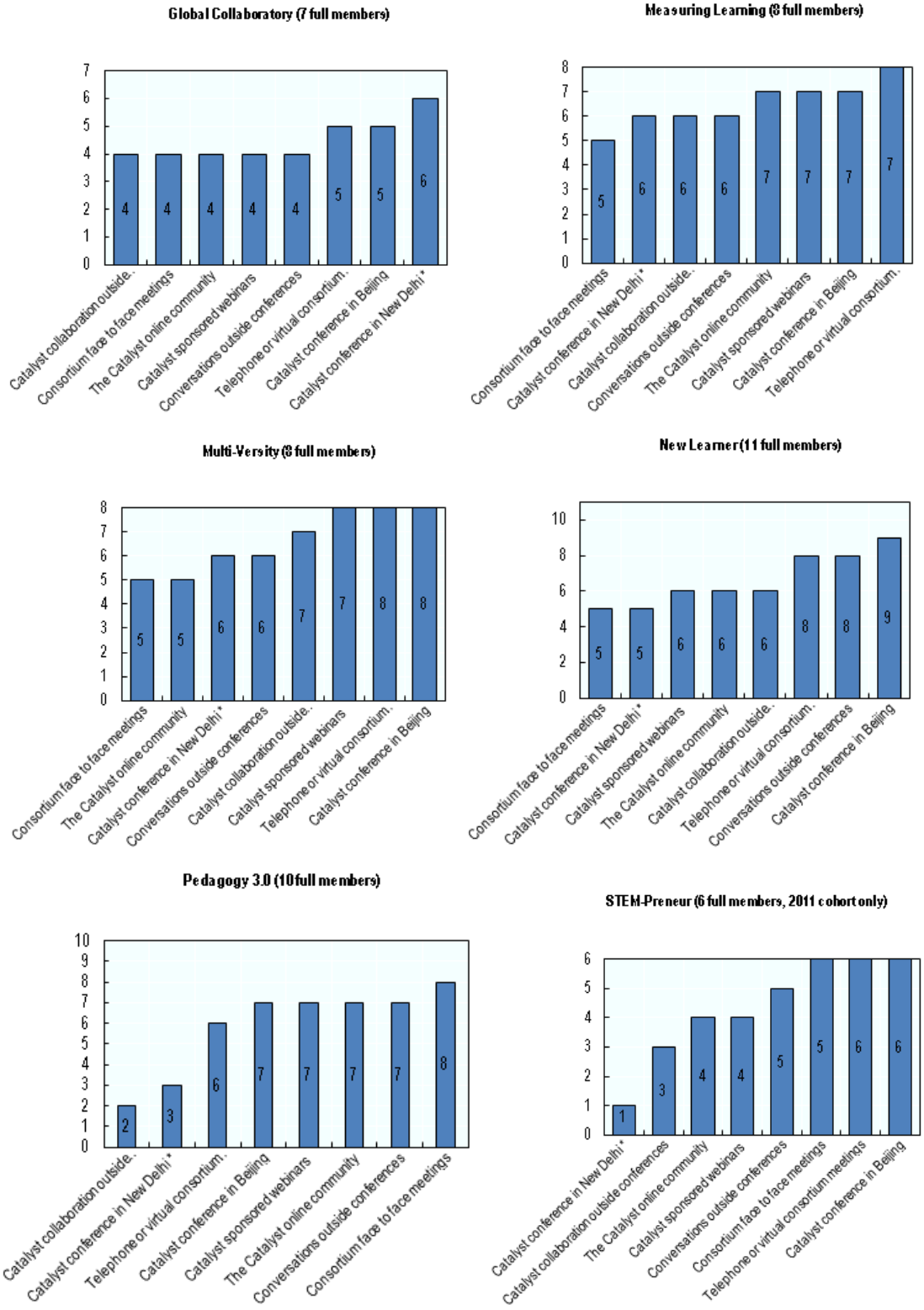
ANNEX S – PARTICIPATION IN COLLABORATIVE ACTIVITIES

Figure S.1. Participation in collaborative activities within the Catalyst Initiative (46 projects)



Source: HP Catalyst Final and First Year Reports (2012).

Figure S.2. Participation in collaborative activities by consortium



ANNEX T – OVERALL FEEDBACK ON THE CATALYST INITIATIVE

Figure T.1. Catalyst Initiative: Perceived strong points (46 projects)

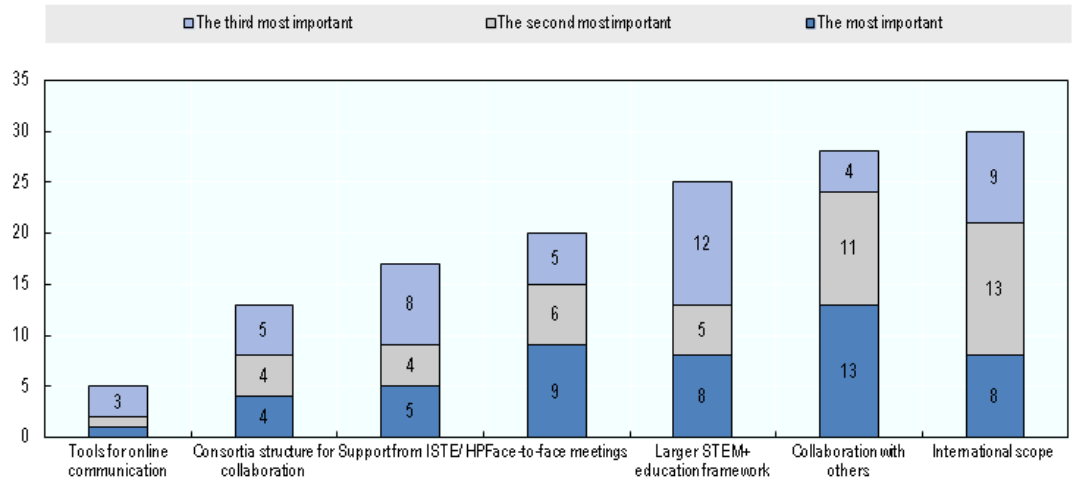
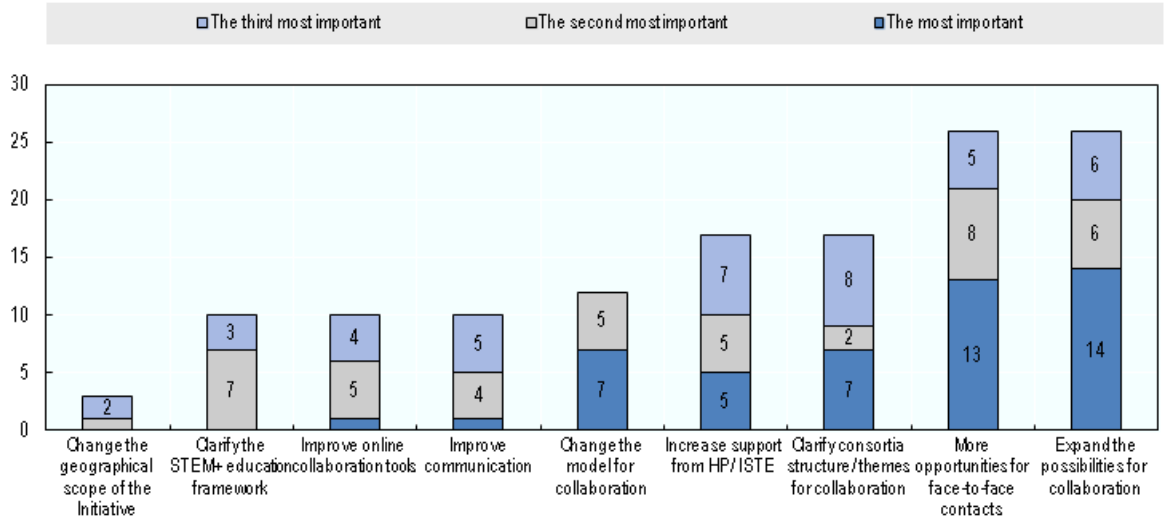


Figure T.2. Catalyst Initiative: Perceived improvement needs (46 projects)



Source: HP Catalyst Final and First Year Reports (2012).

ANNEX U – CONDITIONS FOR COLLABORATION WITHIN THE CATALYST INITIATIVE

Figure U.1. Catalyst Initiative: Factors supporting collaboration (46 projects)

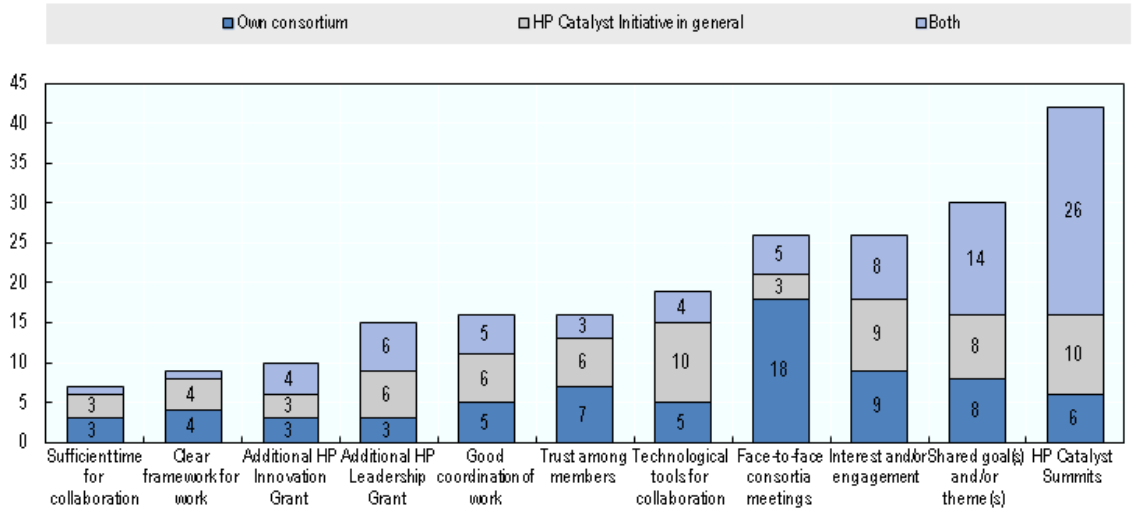
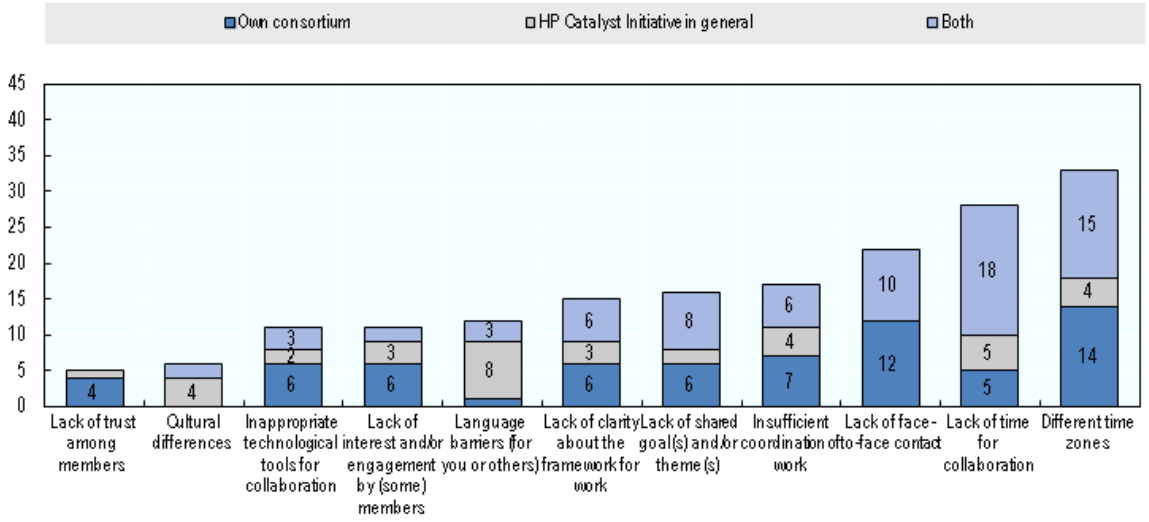


Figure U2. Catalyst Initiative: Factors challenging collaboration (46 projects)



Source: HP Catalyst Final and First Year Reports (2012).

Figure U.3. Factors supporting collaboration by consortium

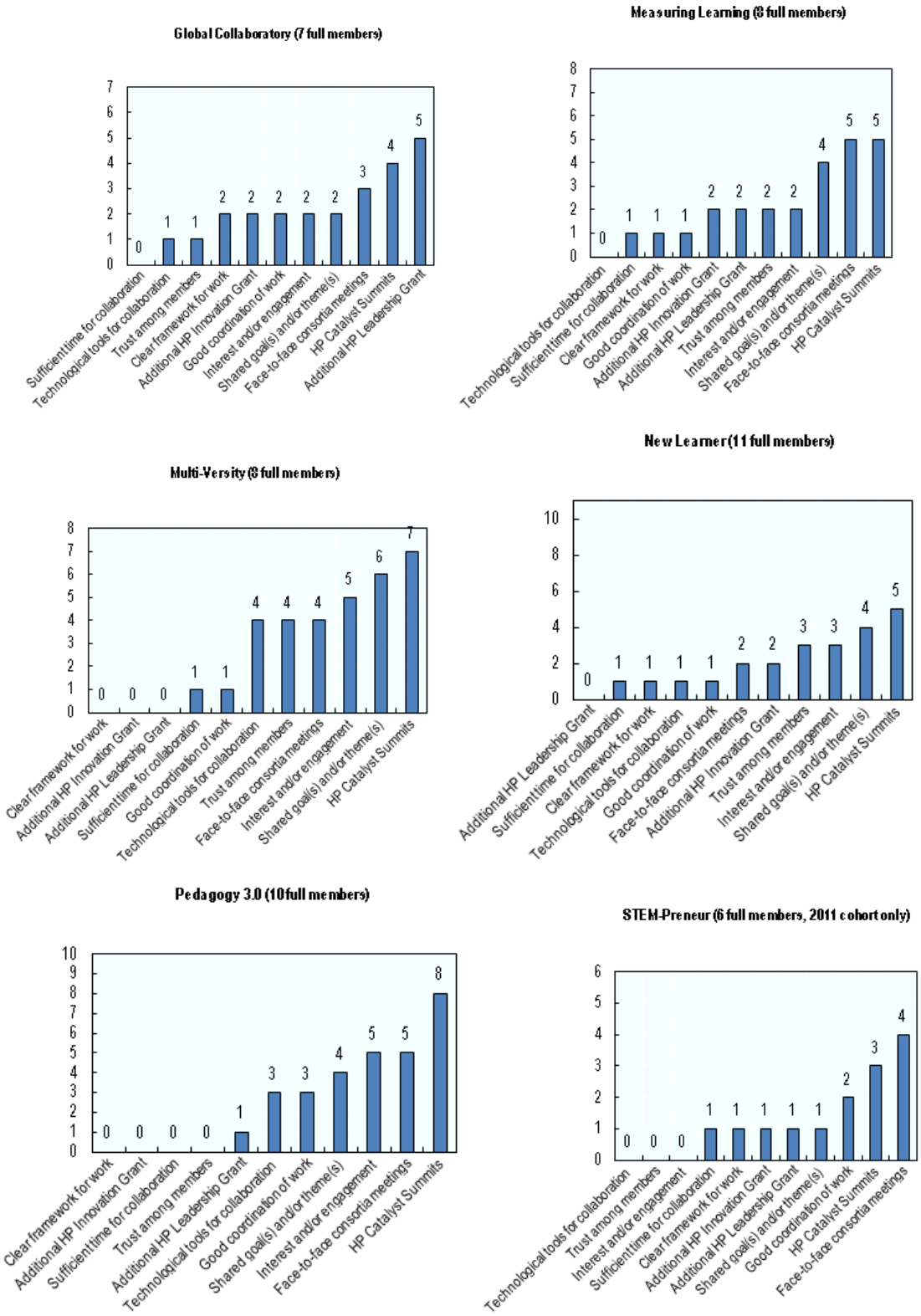
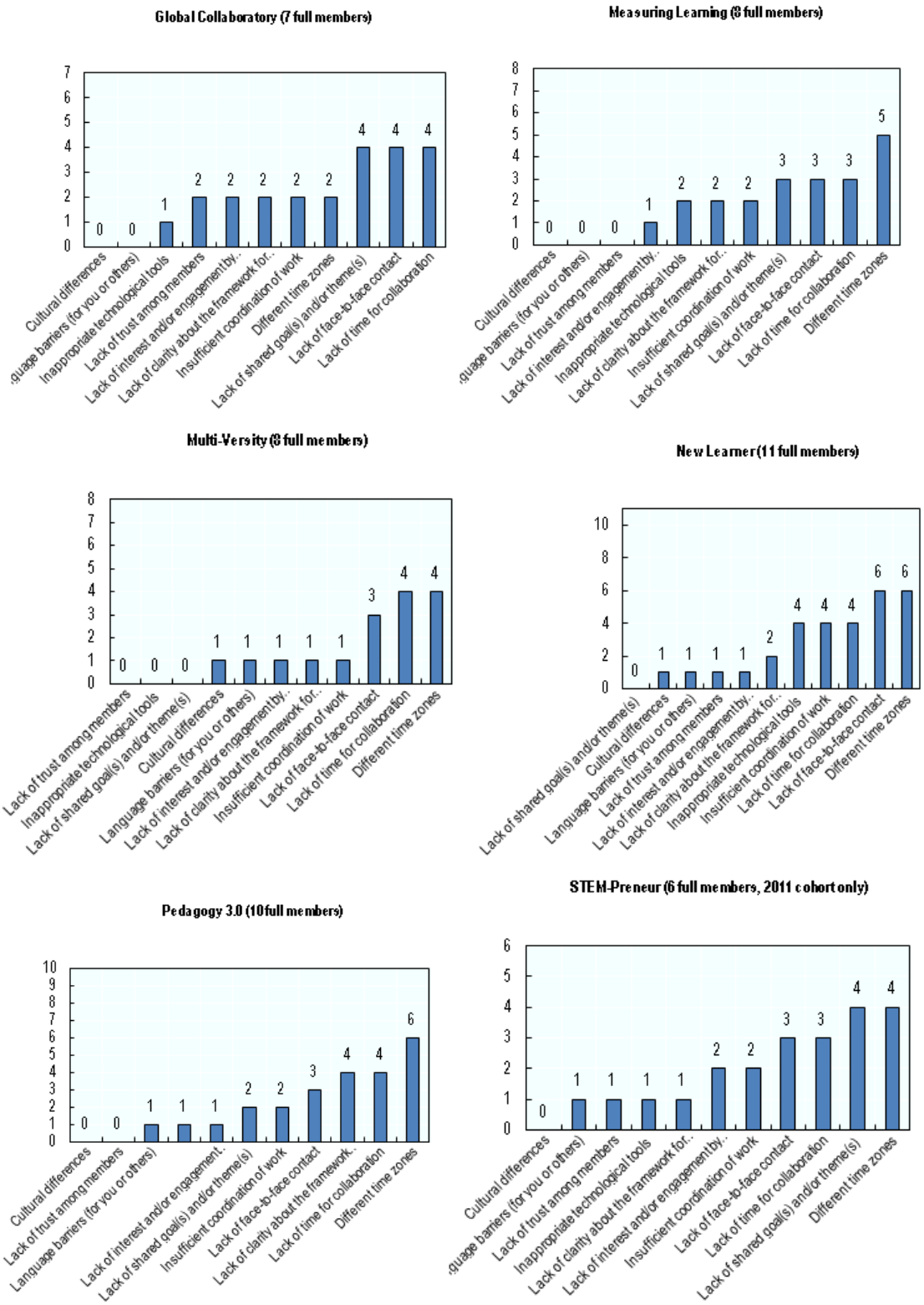


Figure U.4. Factors challenging collaboration by consortium



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Hennessy, S. and S. London (2013), "Learning from International Experiences with Interactive Whiteboards: The Role of Professional Development in Integrating the Technology", *OECD Education Working Papers*, No. 89, OECD Publishing, *http://dx.doi.org/10.1787/5k49chbsnmls-en.*

Kärkkäinen, K. (2012), "Bringing about Curriculum Innovations: Implicit Approaches in the OECD Area", *OECD Education Working Papers*, No. 82, OECD Publishing, *http://dx.doi.org/10.1787/5k95qw8xzl8s-en*.

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