

Education for innovation: the role of arts and STEM education

Workshop Summary Report

OECD/France Workshop, 23-24 May 2011

The OECD/France workshop on education for innovation focused on the role of arts and STEM (Science, Technology, Engineering and Mathematics) education in enhancing skills for innovation.

The objectives of the workshop were to (1) discuss the results and conclusions of a draft OECD report on the impact of arts education on the development of non-artistic skills and (2) explore the state of the art and specify lines of investigation for future work regarding STEM education and its impact on skills for innovation.

This document summarises the key points of the presentations and discussions.

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WORKSHOP SUMMARY REPORT

EDUCATION FOR INNOVATION: THE ROLE OF ARTS AND STEM EDUCATION

OECD/FRANCE WORKSHOP, 23 – 24 MAY 2011

The OECD/France workshop on education for innovation focused on the role of arts and STEM (Science, Technology, Engineering and Mathematics) education in enhancing skills for innovation. The objectives of the workshop were to (1) discuss the results and conclusions of a draft OECD report on the impact of arts education on the development of non-artistic skills and (2) explore the state of the art and specify lines of investigation for future work regarding STEM education and its impact on skills for innovation.

Day 1

Opening remarks

Bernard Hugonnier (OECD Directorate for Education) welcomed the participants and opened the meeting by putting the education for innovation work by the OECD Centre for Educational Research and Innovation (CERI) into a larger OECD context. The horizontal OECD Innovation Strategy demonstrates the capacity of the OECD to conduct thematic work cutting across different sectoral policies. The Innovation Strategy explored how countries can become more innovative for further prosperity and wellbeing – allocating a major role to human capital in fostering innovation. The effectiveness of education systems to deliver skills for innovation needs to be improved. Along the same lines, the OECD Skills Strategy will highlight the need to address the challenge of skills mismatch. Skills and up-skilling for new jobs are all the more important in the context of the economic crisis and globalisation. The ongoing CERI work on arts and STEM education feeds into this effort by exploring what kind of education promotes skills needed by innovative economies. What are the implications for curricula and pedagogies?

Michel Quéré (French Ministry of Education) welcomed the participants on behalf of Luc Chatel, French Minister of Education. He highlighted the importance of innovation in education in promoting skills for innovation. While human capital is central to innovation, education policies need to adjust also to the needs of innovation. Identifying best practices, characterising successful evolution in education and reflecting on the conditions for innovation to occur in education are essential aims for the OECD/France workshop. The meeting should allow participants to reflect about appropriate practices and new initiatives. There are complicated topics to discuss such as: how to combine subject-based knowledge with non-disciplinary skills? To what extent should schools be opened to social environments? What is the role of parents in education and how to best combine it with knowledge learned at school? How can we leverage on the various ways of acquiring knowledge outside of school? These questions need to be explored in order for education to become more open to society. In promoting innovation in education, experiments and their adequate assessment are crucial for improving our knowledge on both innovations and their successful up-scaling across education systems. Advancing our collective understanding on innovation in education is essential. Towards this end, France has established a specific task force within the Ministry of Education to coordinate its contribution to OECD/CERI, including initiatives such as this one related to

managing knowledge on innovation and education. International exchanges are needed to allow us to learn from each other's experiences.

General framework for education for innovation

This session discussed the skills needs for innovation and provided a general introduction to the workshop.

Stéphane Dalmas (INRIA) addressed the issue of skills needs from the standpoint of a research institution. The French government-funded *Institut National de Recherche en Informatique et en Automatique* (INRIA) aims for scientific excellence and knowledge transfer in a highly innovative sector characterised by short innovation cycles. Although neither research nor inventions can be considered as innovations, INRIA's activities are closely intertwined with innovation. INRIA produces knowledge "raw materials" for innovation implicitly through publications as well as by conducting research in partnership with companies. It trains doctorate holders, but is also made up of a highly qualified workforce as the majority of INRIA staff are PhD graduates. The staff enjoys a large scientific freedom (in the context of teams focussing on a specific subject) and teamwork in research is common (both inside and outside the organisations).

The question of who among INRIA staff are the best at innovation can be answered for example by looking at measures of success in technology transfer, research contracts and spin-off creations. Although innovative INRIA staff members cannot be traced back to any specific subject field or background, some common characteristics can be distinguished. The most effective people for innovation are (1) motivated to innovate and (2) have found the right person to talk to. This highlights that acquiring social and behavioural competences are a key issue in converting research into innovation, even if the innovation process is still not fully understood. However, how to best educate and train researchers in these skills for innovation remains a challenge.

Stéphan Vincent-Lancrin (OECD Centre for Educational Research and Innovation) presented the general framework of the OECD/CERI Innovation Strategy for Education and Training project. The project comprises two strands (1) skills and education for innovation and (2) innovation in education. The second strand explores how to stimulate both radical innovation and incremental improvement in education. Focus is put on different drivers of innovation such as research or business as well as on the role of education policy instruments in innovation. The first strand of the project addresses demand, use and supply of skills needed for innovation. Whereas different kinds of skills and qualifications are needed for innovation, those needs may change with future innovation. Certain uses of workforce skills within organisations are associated with more innovation. As to individual skills for innovation, while basic competences such as literacy and numeracy are necessary, other skills can be grouped into the broad categories of (1) subject-based skills, (2) skills in thinking and creativity and (3) behavioural and social skills. Including skills such as creativity, entrepreneurship, curiosity or communication, the grouping departs from classifications such as cognitive/non-cognitive skills and hard/soft skills.

The question with regard to education for innovation is how education policy can better promote the three categories of skills for innovation simultaneously. What should be included in the curriculum and with what emphasis? How should teaching and assessment be changed? Current evidence on the relative importance for innovation of traditional academic competences and other skills is still limited. The ongoing OECD/CERI work focuses on effective and promising practices in arts, STEM and entrepreneurship education, as artists, scientists and entrepreneurs are commonly associated with innovation.

Discussion

The three categories for individual skills for innovation were seen as important, as was the focus on both arts and STEM education.

The discussion highlighted the difficulty to adequately match education policy expectations and instruments with the reality of innovation in education. There can be a misalignment between expectations of radical educational change and the reality of incremental improvement that is much more often observed. An obstacle for innovation in education was seen in the strong emphasis on accountability and testing in some countries that may limit initiative, risk-taking and experimentation by teachers and school leaders.

Keynote addresses

This session explored relationship between education and innovation through two specific initiatives regarding science education and creativity in education.

Pierre Léna (French Academy of Sciences) highlighted the principles and the results of the French *la main à la pâte* initiative led by the French Academy of Sciences and constantly supported by the Ministry of Education. Since 1996, the initiative promotes inquiry-based science education in pre-schools, primary schools and, more recently, in middle-schools through dissemination of materials and support from pilot centres. Its focus is on resources, including e-resources, to coach teachers to change their vision of science and assist them in performing inquiry-based activities. Although the initiative still lacks statistical evidence on its impact on learning outcomes, the initiative has triggered a substantive increase in the provision of science education in primary schools in France. Inquiry is today recommended in the French curriculum, although the practice of it still varies. The initiative has also spread internationally, leading to collaborations with over 50 countries. The leadership by the Academy of Sciences as well as the interest by the Ministry of Education and, in particular, by parents, teachers and media can be seen as some of the success factors of *la main à la pâte*. The future challenges include assessing the impact of the initiative on different competencies of students, coupled with additional tools of formative assessment and professional development for teachers.

Overall, *la main à la pâte* initiative builds on three key principles. First, science education is meant for all students, contrary to the traditional approach in France targeting the needs of future scientists and engineers. Second, the initiative focuses on young students, since neural connections are developed at young age, and curiosity among young children is naturally high. Third, a strong emphasis is put on the relationship between science and language that is seen as a tool for thinking – particularly important for children with lower socio-economic backgrounds. As to skills for innovation, the initiative focuses on learning based on understanding and aims to foster subject-based knowledge through curiosity, observation and manipulation. Inquiry, questioning and forming hypotheses are seen as enhancing thinking skills, while writing, discussing and group work are meant to foster language and social skills.

“Science for all” means that the focus in science education should be on a limited number of “big ideas” – or core knowledge – that all children should master. This implies the structuring of small pieces of knowledge both of science and on science around few big ideas in a way that can be taught in schools. Class observations suggest that the main difference between teachers who do inquiry-based teaching and those who do not lies in how knowledge is progressively structured. As opposed to science seen as a collection of facts, the big ideas are to be progressively built in from pre-school to older children – for example from more direct to less direct evidence and from concrete to abstract – allowing them ultimately to understand also the scientific processes.

Paul Collard (Creativity Culture and Education) presented the Creative Partnerships programme by Creativity Culture and Education (CCE), an independent charity based in the United Kingdom. The program reaches about 10% of schools in England and has developed collaboration with similar initiatives in Europe. Despite the common belief of uniqueness, creativity programmes appear to face similar challenges across countries.

The Creative Partnerships programme comprises diversity of initiatives in UK schools from using drama to teach science to student initiatives to use an airplane as a learning space. The participating schools apply to the programme themselves and maintain the leadership of their own initiative, since the school engagement is seen as a key ingredient of success. CCE then allocates a creative agent – a professional from the creative sector – to work with the school on the issue identified in the school improvement plan. Evaluations of the programme have shown higher attainment and retention of knowledge among students as a result of participating in a creative partnership. The reports by participants suggest improved skills such as self-confidence and communication as well as the importance of unleashing the creativity of the young people by empowering them to implement their ideas themselves. Home school communication and parental engagement appears also to be positively affected by the Creative Partnerships. The positive impact of the programme appears to be the greatest on students from the most deprived backgrounds as well as on schools in the most challenging circumstances. The English Office for Standards in Education, Children's Services and Skills (OFSTED) considers that there is no conflict between national curriculum, core subjects, and the Creativity Program.

A future challenge is developing a language for creativity: To embed creative learning in schools, both teachers and pupils must be able to talk about it confidently, which currently is hardly ever the case. Unlocking creativity is a day by day matter and requires a specific language. CCE is developing video archives of creative behaviour and has an ongoing programme under which creative artists talk to teachers to describe what talent looks like. Is there a language around creativity that less interested teachers also feel comfortable with? Is the language observable and to what extent can it be used to describe progress in creativity? CCE is currently running a research project to answer these questions, in collaboration with OECD/CERI.

Discussion

Identifying the channels by which different skills for innovation are developed is a challenge. For example, although we do not want innovation for the sake of innovation, innovation in education can be a means to foster student and teacher engagement. The question of impact is all the more difficult when taking into account the duration and cumulative nature of education. Different stages of education career can have a varying effect on developing skills for innovation.

The discussion indicated that various policy instruments can be used to support education conducive for skills for innovation. The curriculum can promote science teachers to see the necessary dependence of different topics and progression better, although it is not sufficient condition for change as the curriculum is often not adequately implemented. This highlights the importance of teachers' professional development. Overall, changing the daily practice in education seems to require at least some human contact to support teachers, together with effective school leadership.

Arts education for innovation

This session discussed the existing evidence on the impact of arts education on skills for innovation.

Ellen Winner (Boston College) highlighted the main findings of a draft OECD report on the impact of arts education on skills for innovation. Arts education is often expected to enhance student motivation and

instill cognitive habits that are useful in other contexts outside of the art classroom – although there tends to be little theory behind this expectation. While for example learning to see, learning to envision, and learning to evaluate one's own are some of the habits of mind that have been observed to be taught by visual arts teachers, empirically demonstrating that these are actually learned and then that they transfer to other learning contexts is difficult. Challenges relate both to setting up an adequate experimental study design and the quality of arts education, which has to be strong, as transfer effects are by definition second-order with respect to skill development in the explicitly targeted context.

Many studies claiming to prove the positive impact of arts education on other subjects are in fact correlational studies, and positive causal evidence is rare. No support for a causal conclusion on the transfer effects of arts education was found in 7 out of 10 meta-analyses performed by Ellen Winner and Lois Hetland in 2000. Although correlational studies have shown strong association between multi-arts arts education and academic achievement in the United States, the few existing experimental studies allowing causal inference show no effect. This, together with correlational studies in the Netherlands and the United Kingdom which show no or a negative association, points thus towards non-causal explanations for the correlation between arts education and academic achievement. Students who do well academically may come from families that also value the arts or may attend schools strong in both academics and the arts, for example. There is also little or no empirical evidence demonstrating that arts education has a positive impact on student motivation or on student creativity (measured as a domain general kind of skill using standardised paper and pencil creativity tests). At the same time, there is some evidence for a transfer effect from certain art subjects to other non-arts areas. For example, music has some impact on intelligence quotient (IQ), academic achievement, and phonological skills (which relate to reading ability), and theatre has some impact on verbal skills as well as, possibly, on perspective taking and empathy. Few studies have looked at the effects of "explicit" teaching for transfer, but such teaching might result in stronger transfer effects.

Overall, arts education is important for human development in its own right and should be defended on this basis, whether or not the instrumental justification of the transfer benefits of arts education can be demonstrated. Research has not yet demonstrated that arts education is a means of promoting innovation, creativity or success in non-arts, academic subjects. However, since most of the research on this topic has been poorly designed, further studies on the transfer effect of arts education are needed. These studies ought to build on theoretical hypotheses. Conducting adequate experimental studies in education is very difficult. Ideally studies should be experimental in design, or at least quasi-experimental. If they are correlational in design, care should be taken to control for all important variables besides arts education that could be influencing the outcome, such as IQ, parents' education and income and personality factors.

Discussion

The discussion was launched by Ulrike Giessner-Bogner (KulturKontakt, Austria) and Glenn Schellenberg (University of Toronto).

Participants stressed the need to defend arts education with instrumental arguments, in addition to its intrinsic value. The evidence on proven positive transfer effects of arts education, such as those related to theatre and drama, is therefore important. The increased focus on creativity and innovation provides an opportunity to enhance the role of arts education also with instrumental justifications. Arts education is generally seen as a soft subject that has a weaker position relative to other subjects such as math and reading in the curriculum. Hence, need for arts education may need to be justified more often than for example the need for mathematics education.

The critical tone and caution regarding causality in the draft report were welcomed and some further suggestions provided. Sometimes the report is too critical for example on the impact of music education on

IQ measures of children. Other times the report is not critical enough as some included studies are rather about music attitudes than music education, and because some studies are not weighted by their quality. One needs to pay more attention to the context of arts education and distinguish more clearly between explicitly taught transfer skills and other arts teaching. One could expect more likely to find transfer effect when transfer skills are explicitly taught, and the quality of teaching may impact the transfer. At the same time, everything but explicit teaching to the test can be seen as targeting some kind of transfer.

While the call for experimental studies is reasonable, creating adequate experimental conditions in education with the relevant interventions tested is very difficult. For example, people can be randomly assigned to private music lessons, but then children not practicing for the lessons because they are free for them create an implausible world. Even in the case of experimental studies, isolating causes can be almost impossible considering that the amount of different inputs to education process is large. In this context, good correlation studies can sometimes provide a good substitute for the ideal experimental studies. At the same time, for example treating the school as the experimental unit and randomly assigning classrooms within school to different arts/non-arts training could provide powerful data to detect causal effects. Another way to enhance arts education could be to research its instructional effectiveness and promote its improvement, although finding a common outcome measure for different teaching approaches is difficult. Overall, there is a need to develop assessments of different outcomes, also within arts education.

Music lessons and non-musical abilities

This session explored present research on the impact of music education on academic achievement and other competences.

Glenn Schellenberg (University of Toronto) presented the state of the art on the links between music lessons and cognitive abilities. Unlike other out-of-school activities, participation in music lessons is associated with higher IQ in general. Although many specific associations fade away with the introduction of controls and at the higher education level, the association between music lessons and academic abilities remains significant for younger students.

However, the positive link between music lessons and academic abilities seems true only when music is additional to other endeavours. In the absence of adequate experimental evidence, the strength of the causal relationship remains to be reaffirmed. Indeed, while an experimental study showed higher IQ increases for students taking music lessons than for students in control groups, providing lessons for free created somewhat artificial circumstances such as lack of practice by students. What can then explain the link between music lessons and IQ increases? Conscientiousness, a personality trait that is developed through music lessons, may act as an executive function explaining the improved school performance. As to emotional intelligence, no specific association with music lessons is found.

Day 2

Science education and skills for innovation

This session discussed the results of the recent OECD analysis regarding teaching strategies and skills for innovation in science.

Francesco Avvisati (OECD Centre for Educational Research and Innovation) presented some key findings on skills for innovation and related teaching practices based on PISA data. In addition to cognitive competences, PISA data on science provide information on some other skills for innovation such as scientific motivation, curiosity, and self-confidence. Although some of these indicators such as self-concept can be culturally biased, the measurement of scientific curiosity that is embedded in the cognitive test makes a robust comparison possible. The analysis shows that the ranking of OECD countries

significantly differs when the focus shifts from science test score to the embedded measure of scientific curiosity. Many countries ranking the highest among the OECD countries in terms of PISA science score rank among the lowest regarding interest in science. Only in few countries do students seem to be able to achieve high science scores with high interest in science. To explain this pattern, school cultures seem to play a major role. Indeed, the between-school correlation of average interest and score that is negative in many countries suggests that some school-level variables have diverging effects on curiosity and cognitive achievement in science.

The PISA 2006 survey provides also information on science teaching activities, permitting the analysis of associations between instructional practices and different skills for innovation. Although no instructional practice is highly correlated with science scores, guided hands-on inquiry activities show a more positive association than free inquiry by students, which is in fact negatively associated with test performance. Regarding interest in science, use of real-life applications in science teaching has clearly the highest positive correlation. These associations are robust to controls for many confounding factors. The different pattern of associations with teaching activities that is observed for test scores and interest confirms that these two desirable dimensions of student learning are currently rarely developed together.

Discussion

It would be important to examine the impact of different teaching practices on specific subgroups of students, as the average results may hide some important effects related to students' background. For example, the effectiveness of certain teaching practices on the science scores of students from deprived backgrounds can be different or much more pronounced. Unstructured inquiry practices may have a negative effect on these students, while they may benefit more than an average student from guided inquiry-based teaching.

Caution was called for not making too extensive interpretations on the basis of PISA data. PISA data refer only to teaching during one year, while in reality students have been exposed to teaching for a much longer period. Ideally, the variable of teaching practices should cover a much longer time span.

Effective science education for innovation

This session reviewed and reflected upon the available empirical evidence on effective approaches to science teaching.

Heidi Iverson (Colorado State University) presented a recent meta-analytical work on what works in undergraduate science education. Both experimental and quasi-experimental studies on innovations in undergraduate science education were included in the meta-analysis covering the United States, but also other countries. The examined studies report large effect sizes implying positive impacts of innovation. There are differences between disciplines, but no clear pattern as to type of innovation could be found. The conclusions appear also to be very dependent on the outcome measure. A subsequent analysis on undergraduate physics aimed to limit the comparison to studies sharing a common research design and outcome measure in order to attribute the remaining differences in effect sizes to the intervention. Workshop/studio physics – an instructional approach including for example integrated classroom environment, very structured student work groups and smaller classrooms – stood out as the instructional innovation associated with the largest effect size.

Robin Millar (University of York) reflected on his work regarding effective science education for innovation, drawing on his experience in context-led science course development in the United Kingdom. Adjusting science to school curriculum is a demanding task both from cognitive *and* affective standpoints, especially when it comes to taking into consideration individuality of pupils. The challenge is for students

to develop understanding and see the value of some key elements of consensually accepted knowledge. Context-led science courses aim to hold on to students' interest in science – a crucial element for improving learning. They use real-life contexts where students are or might become interested in science as a starting point to introduce abstract science ideas in a way that demonstrates the usefulness of those ideas.

The school science curriculum needs to develop the scientific literacy of all students while providing the first stages of science training for some students. The primary goal for science education cannot be to train the minority who will go on to study science at higher education, but to focus on the understanding that we would like everyone to have. Scientific literacy means providing students with a toolkit that helps them access, interpret and respond to science as they encounter it in everyday life – for example with emphasis on health or environment as well as on concepts of correlation and causality. Thoughtful everyday encounters with this kind of scientific information require understanding of major scientific ideas and explanations as well as of the nature and methods of science itself.

The development and implementation of a science course for secondary school level with a scientific literacy emphasis has shown that this can be done and that teachers find such an approach feasible and attractive. Emphasis on scientific literacy leads to higher levels of student engagement in science according to teacher reports and students' later course choices. The understanding of the core science ideas is not significantly affected by the contextual focus. Regarding curriculum development, research plays an important role in providing insights, together with practitioners' knowledge – curriculum development should be seen as a process of discovery and knowledge generation. As to curriculum implementation, teachers need considerable support and time to take on new teaching approaches and methods, including improved tools to assess objectives relating to scientific literacy. Given that teaching-to-the-test is inevitable, good tests measuring the desired learning outcomes are essential in making the curriculum operational.

Discussion

The discussion highlighted that science education for innovation requires a very comprehensive approach to its design. A future challenge for science education is to articulate the objectivity of scientific explanations with the subjectivity of science interest as well as to determine an appropriate sequence and structure of themes across the levels of education – possibly including also higher education. Science for future scientists and science for all may require different structures. There may also be some tensions between the structure of the school system – tracking or streaming – and the aim of science – or mathematics – for all. In this regard, primary school may hold an advantage over secondary education in the introduction of science for all as students are not generally tracked. Moreover, teaching is less divided by subjects in primary schools. Although teachers in primary school tend to struggle with their own understanding of science, the high level of specialisation of secondary-school science teachers in some countries can reduce the possibilities to effectively promote science with a science for all approach.

While meta-analysis is a very good methodology to collect and present evidence, it may have limits regarding studies with differing objectives. Another way could be to classify studies according to different objectives instead of instruments of improvement such as technology.

Potential innovative impact of ICT and computer science in education

This session examined recent trends and future possibilities in using ICT to support education for innovation.

Eric Bruillard (*École Normale Supérieure, Cachan*) discussed the potential innovative impact of ICT and computer science in education. Many have predicted rapid evolutions in the education system with

ICT as a lever of change. Education systems are putting increasing emphasis on personalisation and interactivity in learning, extending it to any place at any time with seamless devices – this increases expectations for technology.

Yet, most literature on the impact of technology on education focuses on technological tools rather than on their use by teachers and students. Activities involving technology are rarely analysed and the existing results are not consistent. Some researchers suggest that robust school systems have difficulties to adequately integrate the technology dimension.

Overall, there are several possibilities for the use of technology in innovating education. On the one hand, ICT can be used to empower school management for example through information systems or allow experimentation. It may facilitate resource production and sharing as well as communication by teachers. On the other hand, school and home use of computers by students seems to differ and technology can also reduce real life social contacts with undesired consequences on learning. At the same time, it is difficult to predict what ICT use will be in the future – for example, for the moment communication platforms dominate the use of computers by the youth, but in few years time the situation may be completely different.

Discussion

The discussion highlighted that ICT can be used to enhance student learning in many different ways. For example, as co-operative learning strategies build on the need of students to socialize, ICT could be used to enhance this process. Use of ICT can also introduce a stronger procedural component to student reasoning, in addition to the more traditional conceptual dimension, because the two are intertwined in ICT practice. In the future ICT could be increasingly used for producing objects allowing students to learn that way.

True integration of ICT into schools and classrooms may require the use of technology in exams, so that it becomes a priority in teaching. This is now being done in some countries after use of ICT by teachers was discovered to be weak. It should be kept in mind that ICT use can require redesigning the exercises themselves.

Effective mathematics education for innovation

This session explored existing evidence and experiences on effective mathematics education and skills for innovation.

Jan Terwel (VU University Amsterdam) reflected on co-operative learning in mathematics education by drawing on research projects by VU University Amsterdam as well as on the work of Hans Freudenthal. Whereas the new learning movement aims to draw for example on situated cognition, cognitive apprenticeship, socially shared cognition and community of practice, the movement has its controversies. The ideas of the new learning movement are inspiring, but in reality schools have difficulties in mastering both their background and practical implications.

While educational sciences tend to make an important distinction between providing knowledge (direct instruction) and generating knowledge, VU University Amsterdam has looked for a third way. To this end, the so called AGO model for mathematics education was initially designed and tested and, more recently, the “guided co-construction” model was developed through a series of experiments and projects. In this model, the teacher holds an explicit role in whole class instruction and scaffolding of students. With the focus on cooperative learning, mathematical concepts, principles, models and symbols are constructed based on students’ prior knowledge. Based on testing, the guided co-construction model seems to be both a

feasible and an effective strategy for mathematics education. Some tests have suggested that similar model can work also in natural sciences, in addition to mathematics.

Different theoretical foundations for the effectiveness of co-operative learning in small groups exist. Co-operative learning can raise socio-cognitive conflicts that can in turn be a vehicle for learning. Another possibility is that students share their resources for understanding assignments forcing them to reorganize cognitively their knowledge. Finally, co-operative learning includes a motivational component. As to practical implementation, learning in groups required drastic changes in the curriculum, including curriculum materials such as textbooks. Assignments and exercises need to be redesigned to be suitable for co-operative learning as opposed to the transmission model. Suitable assignments include working with mathematical models or making representations individually or in a group.

Overall, cooperative learning has proved to be both a feasible and an effective model of learning in mathematics in a context of guided co-construction, although some caution is needed. Low achieving students may benefit less from co-operative learning, which should not replace all kinds of instruction. Co-operative learning is to be combined with other instructional strategies. These reflections built on research using quasi experimental design relying on outcome measures both prior and after the educational intervention. The research was spread over part of the year or the whole year.

Remy Jost (French Ministry of Education) discussed his experience on the role of mathematics for innovation and creativity. Creative mathematics activities can be seen as requiring students to solve open-ended problems with several possible solution methods that are not indicated beforehand. This requires students to reason and assess that reasoning. Practicing mathematics includes both acquiring knowledge and solving problems. This implies understanding, taking initiatives, trying methods, using knowledge and procedures, making hypotheses, reasoning and communicating the solution. Students ought to have time to explain what they have tried. Mathematics in France is now designed to go towards this direction.

Regarding implementation, mathematics teachers, however, do not generally consider creativity to be part of mathematics: it is not easy for them to describe what creative mathematics is. Although creativity is mentioned in the curriculum, it is not taken seriously nor considered as a real competence for all students. This is all the more the case as creativity is very difficult to measure and is not part of exams.

Ideally teachers guide the students' own reasoning and search for solutions without imposing their own solution, but this rarely happens in practice. An analysis of PISA survey answers sheets have shown that students in France do not write an idea of resolution when they cannot find the solution.

In the future, one could attempt to measure creativity in several different ways including observing students' problem-solving processes and examining what skills are being developed such as enjoyment in searching and communicating the solution. This could include keeping record of what students have tried and what were the results. At the same time, discussions about mathematics purposes, mathematics clubs, competitive events as well as logical and strategic games could be promoted. As to teachers, one may wish to shift focus in teacher recruitment towards creativity. This would mean recruiting teachers who have already been confronted to research, who like teamwork, who are able to propose open problems, who have good mathematical culture and historical knowledge. A challenge is to enhance the place of innovation and creativity in the French educational system, and to communicate and convince people of the importance of creativity in mathematics teaching.

Discussion

The discussion suggested that similar approaches may be used for enhancing mathematics and science education, as they are very much interlinked, one building on another. There is no science without

mathematics, and mathematics in turn is often developed from scientific problems. Some principles of learning cross disciplinary borders.

It was highlighted that success of any educational intervention depends on the desired outcomes as well as on its context. While it is hard to argue against approaches such as co-operation, inquiry or creativity, the question is rather whether they work or not. The answer to this question depends on the context in which teaching and learning take place as well as on desired and measured outcomes, which are not neutral to value judgments. What are the tasks we wish students to master? How does for example a creative student differ from a non-creative student and what is the role for education to play? Only if we answer these questions first can we determine effective pedagogies.

Regarding implementation, assessments were stressed as a key driver for triggering adequate teaching of skills for innovation: Often, what gets measured gets taught. This implies changing and re-designing exams and tests.

ANNEX 1 – ANNOTATED AGENDA

Education for Innovation: the Role of Arts and STEM Education

OECD / France workshop

23-24 May 2011

Union Internationale des Chemins de Fer U.I.C

16 rue Jean Rey - 75015 Paris

Education and training systems are increasingly under pressure to empower people to innovate and quickly respond to new skills needs generated by innovations. While lack of skills limits the amount and the diffusion of innovation, innovating requires a diverse set of skills that may vary across sectors, organisations and activities. In addition to disciplinary competences, skills such as creativity, critical thinking, and the ability to communicate and work in complex problem-solving teams are vital to innovation. .

Consequently, skills and education for innovation form an essential part of the Innovation Strategy for Education and Training by the OECD Centre for Educational Research and Innovation (CERI). The work on education for innovation brings together research evidence on pedagogies and curricula that foster different individual skills for innovation. The skills for innovation refer to (1) subject-based skills, (2) skills in thinking and creativity as well as (3) behavioural and social skills.

The OECD/France workshop will focus on the role of arts and STEM (Science, Technology, Engineering and Mathematics) education in enhancing skills for innovation. It will draw on recent international empirical evidence and build on the experience of distinguished international experts. Active participation in discussions and exchanges by all participants will be encouraged.

The objectives of the workshop are to:

- discuss the results and conclusions of the draft OECD report on the impact of arts education on the development of non-artistic skills;
- explore the state of the art and specify lines of investigation for CERI's work regarding STEM education and its impact on skills for innovation

The working language of the workshop will be English.

Annotated Agenda

Day 1: Monday 23 May (9:30-17:30)

9.30-9.45: Session 1: Opening remarks

- Bernard Hugonnier (OECD)
- Michel Quéré (Ministère de l'éducation, France).

9.45-10.45: Session 2: Education for innovation: presentation of the general framework

In this session some views about key skills for technological innovation and about how education could better foster these skills will be presented and discussed, before a brief introduction to the general framework of CERI's project "Innovation Strategy for Education and Training". Some of the assumptions and methodology of the project will be presented and discussed.

- Stéphane Dalmas (Institut National de Recherche en Informatique et en Automatique)
- Stéphan Vincent-Lancrin (OECD)

10.45-11.05 : Coffee break

11.05-12.45: Session 3: Keynote addresses

One of the founders of the "La main à la pâte" initiative will speak to how inquiry-based science teaching can contribute to equip children and teachers with subject-based competences, critical thinking, curiosity, and other skills for innovation. We will then explore initiatives that use creativity and culture as drivers of social and educational change. A general discussion will follow.

- Pierre Léna (Académie des Sciences)
- Paul Collard (Creativity Culture & Education)

12.45-14.00: Lunch break

14.00-15.30: Session 4: Arts education for innovation: what do we know?

Arts education is often said to develop skills for innovation, and in particular student creativity. What do we know about its impact on "non-artistic" skills useful for subjects such as mathematics, science or reading? And does it also have a positive impact on student motivation, self-confidence, creativity, and ability to communicate and cooperate effectively? A draft OECD report addressing these questions will be presented and extensively discussed.

- Ellen Winner (Boston College)
- Discussant: Glenn Schellenberg (University of Toronto), Ulrike Giessner-Bogner (Austria)

15.30-15.50: Coffee break

15. 50-16.50: Session 4 (continued)

16.50-17.30: Session 5: Music lessons and nonmusical abilities

This session will present research about music education, academic achievement and other outcomes and reflect on transfer effects.

- Glenn Schellenberg (University of Toronto)

Day 2: Tuesday 24 May (9.00-16.30 - approximate timing below)

9.00-9.45: Session 6: Science education and skills for innovation: evidence from PISA

New OECD research presenting the evidence from PISA on what teaching strategies in science are associated with higher levels of scientific subject-based skills, scientific motivation, curiosity, and self-confidence will be presented and discussed.

-Francesco Avvisati (OECD)

9.45-10.30: Session 7: Effective science education for innovation

This session will convene experts in science education to review and reflect upon the available empirical evidence on effective approaches to developing the different categories of skills for innovation through school science teaching. This session will build a frame for a better understanding of how curricula, pedagogies and assessments can equip learners with a range of competences in addition to subject-based competences, including reasoning, creativity, communication, curiosity, etc.

-Heidi Iverson (University of Colorado at Boulder)

-Robin Millar (Centre for Innovation and Research in Science Education, University of York)

10.30-10.50 : Coffee break

10.50-12.00: Session 7 (continued)

12.00-12.45: Session 8: Potential innovative impact of ICT and computer science in education

This session will review old and more recent trends about contribution of technologies in school activities with an oriented view towards innovation competencies. The role of ICT in innovating STEM education will then be discussed.

-Eric Bruillard (ENS Cachan)

12.45-14.00: Lunch break

14.00-16.00: Session 9: Effective mathematics education for innovation

This session will convene experts in mathematics education to discuss effective mathematics education. The evidence about improving subject-based skills and the prevention of mathematics anxiety will be reviewed, as well as pedagogies or curricula associated with better reasoning-, creativity- and behavioural/social skills. Differences with science teaching will be highlighted and discussed.

-Jan Terwel (VU University Amsterdam)

-Rémy Jost (French Ministry of Education)

16.00-16.30: Session 10: Final discussion and next steps

The final session will bring together the main themes and findings of the workshop, discuss the similarities and differences across subject matters. It will also identify promising lines of enquiries to inform education policy makers about evidence-based educational practices fostering skills for innovation.

16.30: Close of meeting

ANNEX 2 – LIST OF PARTICIPANTS

Participants list for the workshop*Education for Innovation: the role of Arts and STEM education***Liste des participants pour le séminaire***L'éducation pour l'innovation : le rôle de l'éducation artistique et scientifique*

23/5/2011 - 24/5/2011

Austria/Autriche	Mrs. Ulrike GIESSNER-BOGNER KulturKontakt Head of Department for Arts and Cultural Education
Belgium/Belgique	Ms. Rita DUNON Department of Education and Training Policy Advisor
Canada	Mr. Glenn SCHELLENBERG University of Toronto Mississauga Professor
France	Mr. Eric BRUILLARD Ecole Normale Supérieure Cachan Professor
	Mr. Stéphane DALMAS Institut National de Recherche en Informatique et en Automatique Head of operations
	Mr. Patrice DURAND Ministry of Education In charge of Sciences
	Mr. David JASMIN La main à la pâte Director
	Mr. Rémy JOST Ministry of Education Expert in mathematics
	Mr. Jean-Baptiste LAGRANGE Université de Reims Professor
	Ms. Florence LEFRESNE Ministry of Education Chef de la mission aux relations européennes et internationales (MIREI)

Ms. Anne LEJEUNE
La main à la pâte
International relations manager

Mr. Pierre LENA
Université Paris Diderot et Académie des Sciences
Emeritus Professor

Mrs. Catherine MARMIESSE
Ministry of Education
In charge of educational innovations and experimentations

Mr. Xavier PERSON
La main à la pâte
International relations manager

Mr. Michel QUERE
Ministry of Education
Director for Evaluation, Foresight and Performance

Mr. Claude SAUVAGEOT
Ministère de l'Enseignement supérieur et de la Recherche
Conseiller auprès du directeur

Germany/Allemagne

Mr. Peter BAPTIST
University of Bayreuth
Head of the chair of Mathematics and Mathematics Education

Mr. Ernst WAGNER
University of Erlangen-Nuremberg
Chair in Arts and Culture in Education - Executive coordinator

Ms. Jeannette WEISSCHUH
Hewlett Packard Corporation
Director of Education Initiatives

Netherlands/Pays-Bas

Mr. Teunis IJDENS
Cultuurnetwerk
Senior project manager and consultant

Mr. Jan TERWEL
VU University Amsterdam - Faculty of Psychology and Education
Professor Emeritus of Education

Slovenia/Slovénie

Mrs. Sasa KREGAR
The National Education Institute
Senior Consultant for Biology

United Kingdom/Royaume-Uni

Mr. Paul COLLARD
Creativity Culture and Education

Chief Executive

Mr. Robin MILLAR
University of York
Professor of Science Education

United States/États-Unis

Mr. Anders HEDBERG
National Science Resources Center (NSRC) International
Coalition/Hedberg Consulting LLC
Chair/President

Ms. Heidi IVERSON
Colorado State University
Postdoctoral Fellow

Ms. Ellen WINNER
Boston College
Chairman at the Department of Psychology

**Trade Union Advisory
Committee
(TUAC)/Commission
syndicale consultative
(TUAC)**

Mr. Anders VIND
Danish Confederation of Trade Unions
Consultant

**Business and Industry
Advisory Committee
(BIAC)/Comité consultatif
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(BIAC)**

Mr. Jonathan GREENHILL
Business and Industry Advisory Committee
Policy Consultant

Ms. Tianne GROENEVELD
Business and Industry Advisory Committee
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