Creativity in Science and Mathematics Education for Young Children: Executive Summary

The project CREATIVE LITTLE SCIENTISTS has received funding from the European Union's Seventh Framework Programme (FP7/2007-2013) for research, technological development and demonstration under grant agreement no 289081.

This Executive Summary is based on the Creative Little Scientists *Final Report (Deliverable D6.5) which can be found on www.creative-little-scientists.eu.*

Published by **Ellinogermaniki Agogi**

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Printed by:

ISBN Number:

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Introduction

Creative Little Scientists was a 30-month EU funded comparative study working across nine participating countries: Belgium, Finland, France, Germany, Greece, Malta, Portugal, Romania and the UK. The *Creative Little Scientists* project sought to build a picture of policy and practice in science and mathematics education for children aged 3-8 and their potential to foster creativity and inquiry learning and teaching.

The project aimed to add to previous EU reports in science and mathematics education in its focus on the nature of science and mathematics education in the *early years* and in seeking to characterise and investigate opportunities for *creativity in learning and teaching* within the specific contexts of science and mathematics. A significant strand of the project was also the development of guidelines for policy and teacher education building on findings from the different phases of the study and ongoing collaboration and dialogue with participants and other stakeholders. The study aimed to mainstream good practices by proposing changes in teacher education and classrooms encompassing curriculum, pedagogy and assessment.

Episode 'Sandbox' (3 years old) (Belgium): Making a wall

In the sand corner the teacher had placed materials to build with, including real bricks and other specialist tools to help with the building process such as plaster, trowels and spirit levels, as well as the familiar buckets and spades.

The activity presented the children with several problems. They were given space and time to *generate their own solutions.* There were opportunities for collaboration between children as they played and watched what each other did. They made decisions based on observations and *evaluation of evidence* of the impact of their actions demonstrating creativity in *making connections* and in their *reasoning skills.*

First the two children worked separately to make their own walls. However after some time they started working together to build one wall, sharing the tasks required to prepare their materials.

One child was pouring out the water to mix with the sand when she noticed that the sand was not mixing enough with such a large amount of water and so she poured some of the water out of her bucket. Her action suggested creativity in *modifying her approach* based on her *observations.*

The other child *observed* this effect and only put a little bit of water on the sand in his bucket, indicating that he had *used the evidence* from his partner's mixture to make decisions about his own mixture.

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Core drivers for *Creative Little Scientists*

The project was informed by at least four key drivers that set the context for an increased research focus on science and mathematics education and creativity in the early years classroom:

- **The role of an economic imperative within education**, demanding capable scientists and creative thinkers in an increasingly knowledge-based globalised economy, which requires certain capabilities in the classroom, including reasoning skills, innovative thinking and positive attitudes.
- **The role played by science, mathematics and creativity in the development of children and of citizens**.
- **The role of early years education in building on children's early experiences and in promoting positive skills and dispositions**.
- **The role of a digital or technological imperative within education**.

Alongside these wider societal issues, the project was informed by changing perspectives on children and increased awareness of the child as an active and competent meaning-maker. There is increasing recognition of children's capacities to take ownership of their own learning and take part in decision making in matters that affect their lives in the present.

Episode 'Building blocks' (5 years old) (Germany): Building the "Leaning Tower of Pisa"

The teacher had observed that the class of 5-year old children enjoyed playing with wooden building blocks. To extend their learning she gave the children a book with photographs of buildings. Inspired by these the children decided to build the "Leaning Tower of Pisa" showing creativity in their *sense of initiative* and *imagination* in *generating* plans for a new building project.

One child started off with a plan but the tower tumbled down. The teacher encouraged the child to *reflect* on the source of the problem and then stood back while the child worked with another child to find a solution. The children *observed, predicted* and *communicated* their ideas demonstrating creative dispositions such as *making connections* between observations and using *reasoning skills* in coming up with a solution

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Contribution of the Conceptual Framework

In drawing together a review of policy-related and research-related literature covering fields including science and mathematics education in the early years, creativity in education, creativity as a lifelong skill, teaching and teacher training approaches, as well as cognitive psychology and comparative education, the project's Conceptual Framework provided a strong theoretical framework for the study.

Two particular features of the Conceptual Framework played key roles in fostering coherence and consistency in approach across the project and in themselves have the potential to contribute to future work in the field, the *definition of creativity* in early science and mathematics employed across the project and the *synergies* identified between inquiry based and creative approaches to learning and teaching, drawn from the reviews of science and mathematics education in the early years and creativity in education. The definition of creativity in early science and mathematics developed from the Conceptual Framework and subsequently refined through discussion with stakeholders is: *Generating ideas and strategies as an individual or community, reasoning critically between these and producing plausible explanations and strategies consistent with the available evidence*. This needs to be understood alongside the 'Little c creativity' definition (Craft, 2001), as in the diagram below (Figure 1) insofar as this effort toward originality and value through imaginative activity drives creativity in other domains including early mathematics and science.

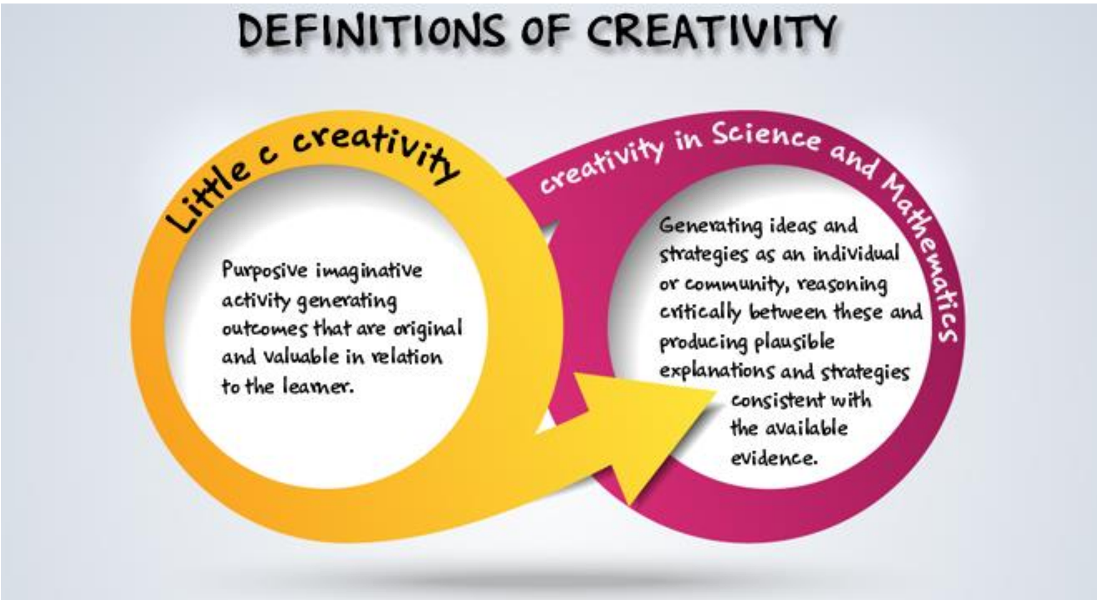

Figure 1: 'Creative Little Scientists' definition of creativity in early years science and mathematics education

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**Episode 'Gloop' (4-5 years old) (Northern Ireland):
Exploring the properties of gloop, using different tools**

In this activity children aged 4-5 years old were involved making and exploring 'gloop' – mixing water and corn flour in a large plastic tray that had been placed on a table. Children were free to attend and leave the activity as they pleased. After a short time, the teaching assistant placed a number of different tools - for example spatulas of varying sizes, rubber paint brushes, a funnel – into the tray to further provoke interest and exploration.

One child became immersed in this activity over a long period, *observing* the mixture, and *trying out different ways* to use the tools and their effects, for example scooping it with spatulas or drawing in it with the rubber-tipped paint-brushes. Creativity was evident in his *curiosity* and *sense of intiative* and in the question implicit in his actions *"What can I do with this?"* This was particularly apparent when analysing Ryan's observable contemplation and subsequent use of tools in the tray. At one point, he was moving gloop across the tray with a wide spatula in his right hand, then trying to stop its return flow using a rubber paintbrush in his left hand. At another point he was scooping up the cornflour mix with the spatula and slowly dribbling it on to his forearm and hand. This *generation of alternative strategies* and ways to use the tools provided often novel and unexpected outcomes.

The project identified *synergies and differences between inquiry based science education and creative approaches* (Figure 2). The definition of creativity as above, and the synergies between inquiry based and creative approaches, have been empirically tested in diverse classroom contexts across Europe throughout the project and have been found to be both appropriate and valid across geographic and age contexts (3-8). They have also proved productive and of interest more widely in the dissemination of the work of the project with varied stakeholders across and beyond Europe, including researchers, teachers and teacher educators.

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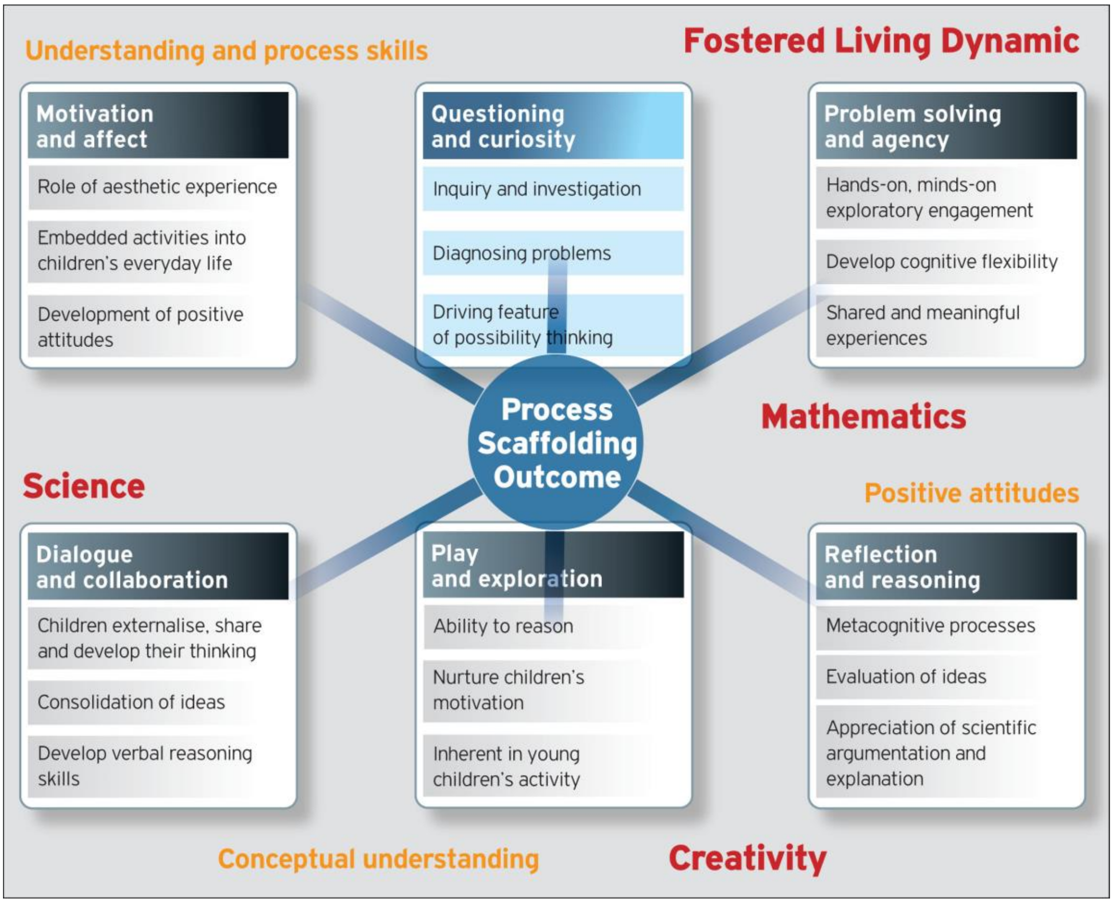

Figure 2: A diagram to represent the pedagogical synergies between creativity, science and mathematics in early years education

The *Conceptual Framework* identified three broad strands that might be addressed across the phases of the project namely: *Aims, purposes and priorities*; *Teaching, learning and assessment*; and *Contextual factors*. These were further elaborated drawing on the *curriculum dimensions* associated with the 'vulnerable spider web' (Figure 3), which identifies key questions about aspects of learning in schools (van den Akker, 2007). The rationale in the middle of the spider web refers to the central mission of the curriculum. It is the major orientation point for curriculum design, and the nine other components are ideally linked to the rationale and preferably consistent with each other. The spider web illustrates the many interactions and interdependence of the parts but also the vulnerability. If you pull or pay too much attention to one of the components, the spider web breaks (van den Akker, 2007, p41).

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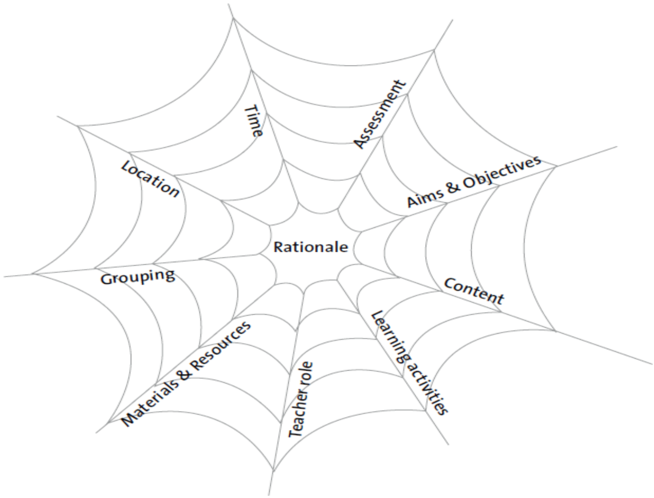

Figure 3: Curricular Spider Web (van den Akker, 2007, p. 41)

The review of research findings related to creativity in learning and teaching was used to develop a List of Factors linked to these different dimensions that had been found to be associated with creativity in early science and mathematics. The curriculum dimensions and associated List of Factors provided an essential common framework across the different phases of research in capturing an in-depth empirical picture of conceptualisations, practices and outcomes related to opportunities for creativity in early science and mathematics.

Research questions and approach

The *Creative Little Scientists* project aimed to identify and characterise what, if any, creativity is evidenced in early science and mathematics (in relation both to children's learning, and teachers' pedagogy). As a consequence the study sought to produce a description or map of lived experience in Early Years science and mathematics education and to articulate what creativity in early science and mathematics looked like.

To reflect the conceptual and research foci and methodological framing developed in the Conceptual Framework, the research questions were framed around:

- *capturing conceptualisations*
- *evidencing practice*
- *developing practice*

and were:

RQ1. How are the teaching, learning and assessment of science and mathematics in Early Years in the partner countries **conceptualised** by teachers and in policy? What role if any does creativity play in these?

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RQ2. What **approaches** are used in the teaching, learning and assessment of science and mathematics in Early Years in the partner countries? What role if any does creativity play in these?

RQ3. In what ways do these approaches seek to **foster young children's learning and motivation in science and mathematics**? How do teachers perceive their role in doing so?

RQ4. How can findings emerging from analysis in relation to questions 1-3 inform the development of practice in the classroom and in teacher education (Initial Teacher Education (ITE) and Continuing Professional Development (CPD))?

These questions were examined in relation to the curriculum dimensions and associated List of Factors found to be associated with creativity in early science and mathematics. In addition, for this study, these dimensions were grouped to reflect the two main foci of the fieldwork, informed by the pedagogical model developed by Siraj-Blatchford et al (2002) shown in Figure 4, namely

- **Pedagogical interventions** (or interactions) documented by observing face to face classroom practice and listening to children's reflections on this; and
- **Pedagogical framing** documented through teacher's reflections on classroom practice and wider information concerning the teacher, school, curriculum and assessment.

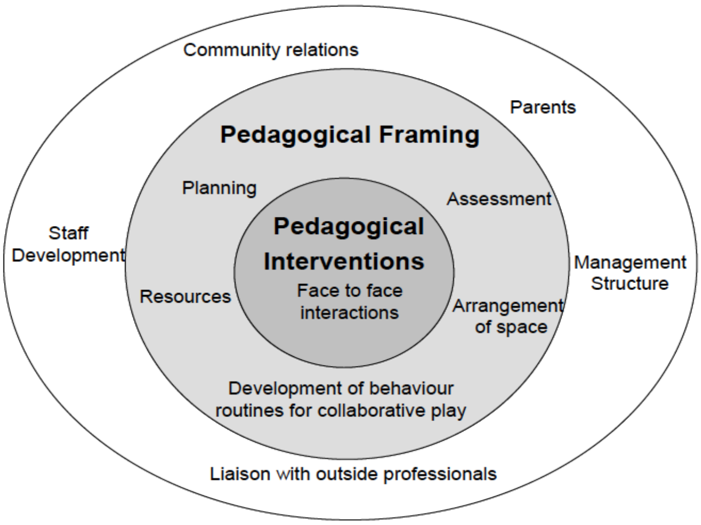

Figure 4: Pedagogical interventions in context (Siraj-Blatchford et al, 2002)

The study also drew on wider contextual information concerning the teachers and schools and early years settings that participated in the fieldwork, and local curriculum and assessment policy to identify any enabling factors or barriers at the contextual level that might influence opportunities for creativity and inquiry in early science and mathematics.

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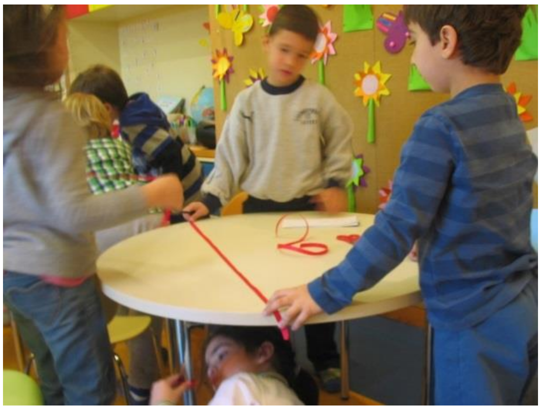
Episode 'Measuring Tables' (5-6 years old)(Greece): Taking measurements to give the carpenter for their new tables



The teacher asked the children (aged 5 and 6) to help her in giving the carpenter measurements to create new worktables for the classroom, identical to the current ones. The children collaborated in small groups to *generate their own strategies* to solve the problem for example *choosing the measuring tools* to use, working out how to *take* and most importantly *record measurements* in their group notebooks. They then had to *present and explain their findings to the whole class*, including the tools they used and how the measurements were made. Finally the children *evaluated and reflected on the activity*: what problems they had faced, how they felt about these and how they had overcome them. In their engagement with this problem-solving activity children demonstrated a range of dispositions associated with creativity including *imagination* in appreciating what the carpenter might require, *creative thinking* in coming up with *alternative approaches* to measuring and recording and *reasoning skills* in evaluating different approaches and outcomes reported.

The *Creative Little Scientists* project was organized into different phases, each of which produced public 'deliverables' (Figure 5), which are available on the website.

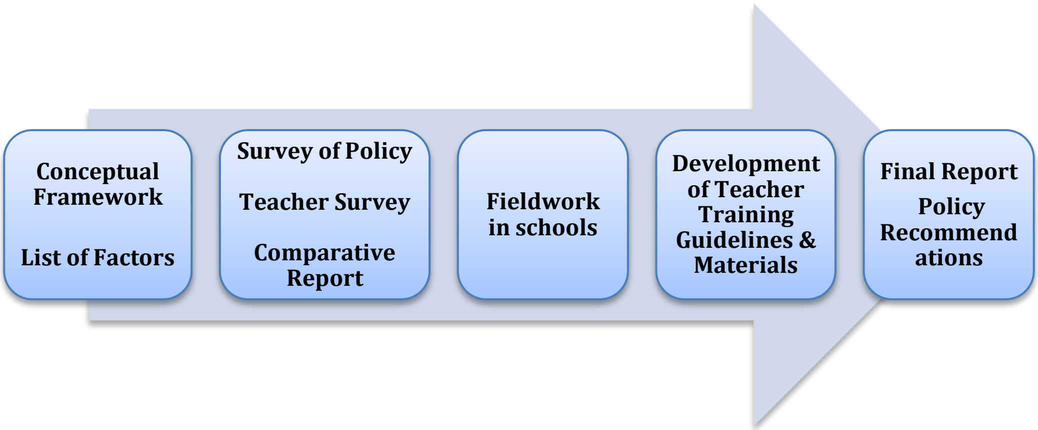


Figure 5: Key deliverables available on the website

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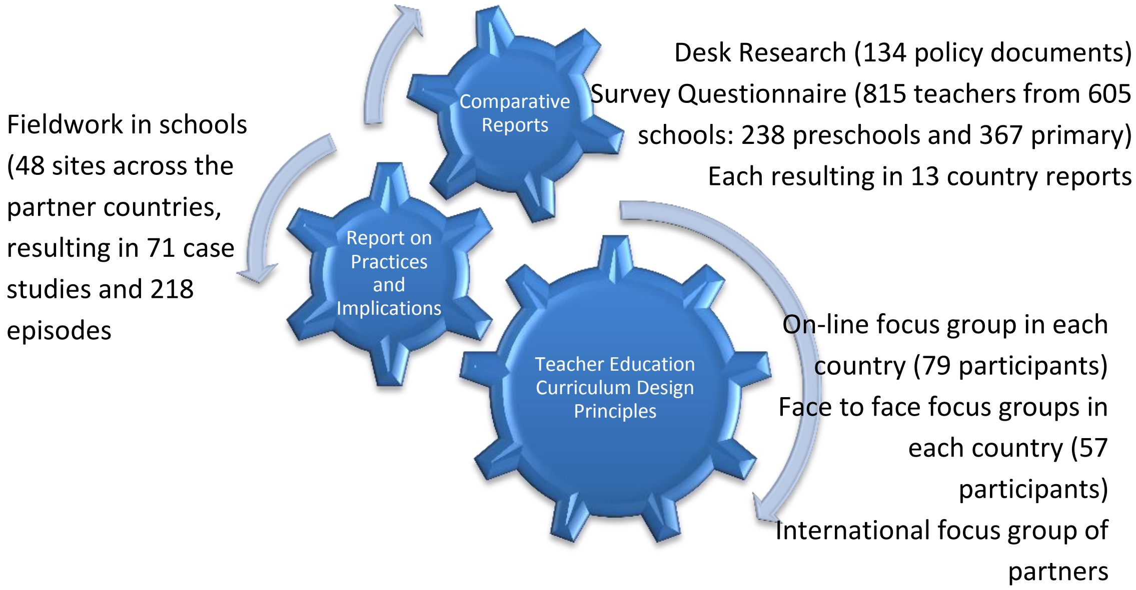

Figure 6: Interaction between the research phases

To meet the project's objectives and research questions, mixed methods were employed, combining quantitative approaches used in the surveys of policy and of teachers' views based on a list of factors, alongside qualitative approaches employed in the case studies of classroom practice and iterative processes associated with teacher education curriculum design research (Figure 6). It was also recognized that policy and practice needed to be interpreted within partners' particular national contexts, especially when making comparative judgments. As a result all phases of research were undertaken by local researchers and reported in separate National Reports. These were then synthesized to form overall *Creative Little Scientists* project reports, which are available on the website.

Methodological issues and challenges

There were a number of methodological challenges and issues associated with collaboration across such a diverse partnership, the collection of a wide range of data to address the project objectives and research questions, and production of project reports within a very tight time frame. Brief indications of these challenges and the course taken by the project to tackle them are shown below.

From the outset language was a key challenge, common in comparative policy studies across countries. Terms such as 'Inquiry' or 'Creativity' do not translate easily between countries; even if terms appear comparable, they may differ in the meaning attributed. Therefore, making comparisons by measuring the use, or absence, of particular terms is problematic. Furthermore, it is very possible that educational policy or practice in a country embodies much of what is signified by a word without

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using this word explicitly. This is highly relevant for examining the term ‘creativity’, where its role may not be reflected by explicit use of the term. It was therefore important for the project to give attention to implicit as well as explicit references to creativity drawing on definitions from the Conceptual Framework.

Episode ‘Float and Sink’ (5-6 years old) (Romania):
How can the dove rescue the little ant who fell into the river?

The teacher told a story to her class of children aged 5 and 6 about an ant who fell into the river. A dove flying by wanted to help the ant. By providing an inquiry-based problem that had more than one solution and by giving children autonomy to come up with their own ideas, the children were able to plan their investigations and showed creativity in *generating their own ideas* about which materials to use and how to test them, using their *imagination* and *making connections* with prior experiences. The children discussed natural materials in the forest the dove might use to help keep the ant afloat. A variety of materials was made available, including nuts, feathers, wooden sticks, leaves, little stones, acorns, pieces of bark, fir cones. Each group discussed *their own predictions* about the materials they thought most suitable to save the ant. They were given small containers with water to test their ideas about which materials in the forest could be used as little ‘boats’ for the ant. Children were able to record and communicate findings *in their own ways*. Children shared and *evaluated* their findings, *drawing on evidence from their observations*, to *justify conclusions* about whether this object would be appropriate to help save the ant.

In relation to conducting an international comparative policy survey an initial issue is to identify what is meant by national policies. It is important first to clarify the different jurisdictions across the participating countries. Then given the wide range of policy documentation and varied degrees of regulation, researchers need to make judgments about the documents that best capture the focus of the study. For the project this was curriculum, assessment and pedagogy in early science and mathematics, and could include for example generic or phase specific policies alongside subject specific documentation. Policy in a number of countries was in transition and it was necessary to review previous or future policy documents that might be in operation during fieldwork. Coding and rating the documents according to the survey tool is also not straightforward. Particularly in relation to rating the emphasis on creativity the project’s Conceptual Framework and dialogue between partners provided vital support. Partners were asked to provide policy references and comments to support their ratings.

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In relation to the teacher survey, motivating teachers to participate is a well known issue. Partners indicated a number of factors that may have contributed to this, including the timing of the survey in the school term, attitudes to research participation, pressures on teachers in particular policy contexts, and the extent of partners' networks and previous contacts with schools.

Core Instruments for Fieldwork

Observation with fieldnotes and a timeline

Sequential digital images taken during the observation

Audio recordings

A map of the space

Individual interviews with teachers

Group interviews with children

Learning walks with children

Artefacts (such as children's work)

The fieldwork was ambitious in seeking to gain insights into school and classroom contexts, learning and teaching processes in classrooms and the perspectives of children and teachers. The project adopted a common framework of ethical requirements including informed consent (staff, parents and children), confidentiality and anonymity, and protocols concerning data protection, storage and publication. Use of photographs was particularly sensitive. In all cases approval needed to be gained from partners' own institutions and in some cases from local or national education authorities. Core instruments employed needed to be practical in all national contexts; in particular a key concern was to devise ways in which to gain insights into young children's capabilities and thinking that could be employed across all settings. To ensure consistency a *Training Workshop* including a fieldwork visit was organized for all researchers involved to introduce and trial methods and approaches to analysis accompanied by a detailed fieldwork manual with background information about each of the fieldwork techniques to be employed. Small peer mentoring groups were set up at this workshop and sustained across the remainder of the data collection, analysis and interpretation phases of the study with team leaders in each conferring with the other team leaders to ensure consistency between researchers' work.

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Episode: 'Counting Minibeasts' (4-5 years old) (England): Children designing their own methods of counting

Children aged 4 and 5 were given the problem of working out how to sort, count and record the number of plastic minibeasts in a bucket. Some children worked in pairs, others individually in a carpeted area of the classroom. The children were given time to *generate their own strategies* for counting the minibeasts and plenty of space to set out and represent sorting and counting processes in *different* ways. They were able to leave their different minibeasts in different areas of the carpet without having to clear their working space each time they finished counting each type. This allowed children to learn from each others' approaches, and for the teacher to examine everyone's work at any point during the activity. Children's *imagination* and *creative thinking skills* were demonstrated in the variety of approaches adopted. For example, one child counted the spiders and flies by placing them carefully in rows of five (as shown in the photograph), whereas another pair of children placed all the flies in a single half-circle row (although they later started adopting the 5 in a row formation for their caterpillars and woodlice). Children were encouraged to *discuss and reflect on* their different strategies with their talk partners at the end of the lesson. The child whose work is shown was overheard saying to his talking partner *"When you're lining them up … 'cause you know when you're lining them up, and there's only one … I don't know where to put it".* Looking at his work he has four rows of five dragonflies (and of spiders) with one remaining dragonfly being placed on the end of a row. He seemed to be grappling with how to deal with remainders.

Findings from fieldwork in classrooms informed the development of the teacher education *Curriculum Design Principles* and *Teacher Outcomes*. Selected data and analysis from fieldwork also provided the basis for the *Teacher Training Materials*. Researchers selected specific **episodes**, which could be used as stand-alone materials in the development of ITE or CPD programmes. One of the biggest challenges in this respect was in ensuring that episodes could be understood out of the context of the setting in which it took place. Also, as the remit for ITE and CPD is somewhat different, it was important that the *Teacher Training Materials* could effectively be utilized for both. A large collection of **templates** was subsequently developed, which relate to specific aspects of the *Teacher Outcomes* associated with the *Content* dimension of the *Curriculum Design Principles* (see Figure 7). These episodes and templates are available on the *Creative Little Scientists* website, along with the report on *Exemplary Teacher Training Materials*, which explains how to use these materials.

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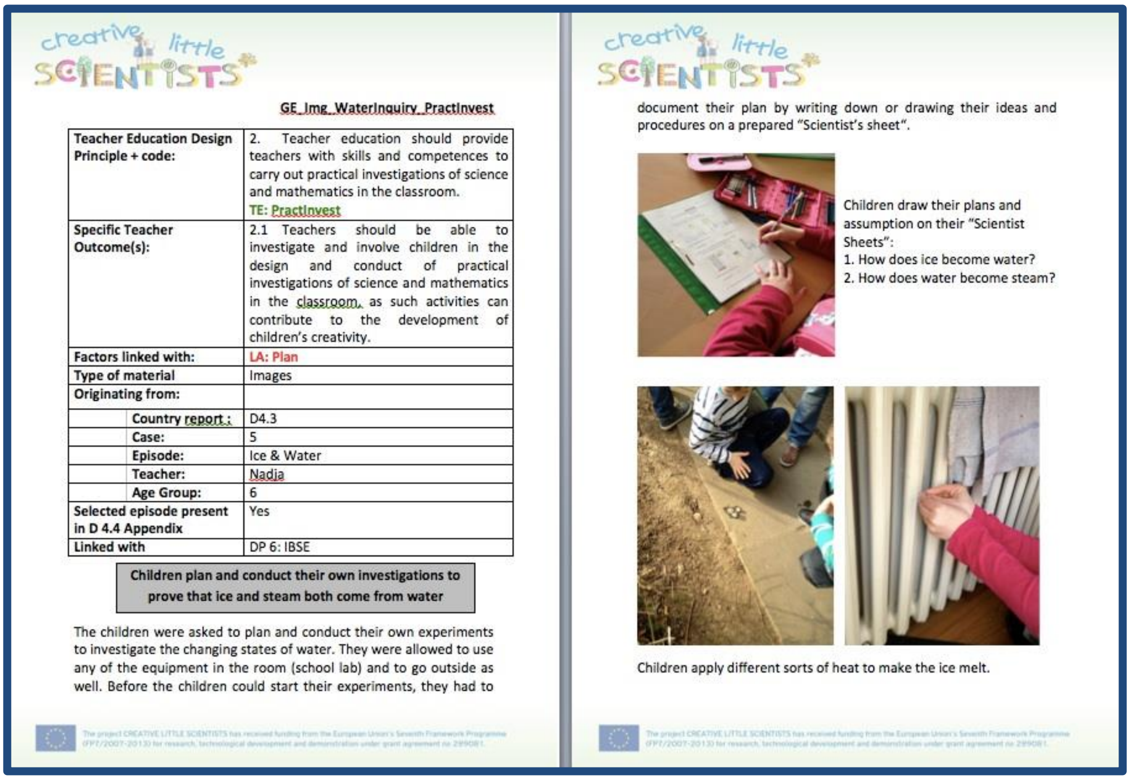

GE_Img_WaterInquiry_PractInvest

Teacher Education Design Principle + code:		2. Teacher education should provide teachers with skills and competences to carry out practical investigations of science and mathematics in the classroom. TE: PractInvest
Specific Teacher Outcome(s):		2.1 Teachers should be able to investigate and involve children in the design and conduct of practical investigations of science and mathematics in the classroom, as such activities can contribute to the development of children's creativity.
Factors linked with:		LA: Plan
Type of material		Images
Originating from:		
	Country report :	D4.3
	Case:	5
	Episode:	Ice & Water
	Teacher:	Nadja
	Age Group:	6
Selected episode present in D 4.4 Appendix		Yes
Linked with		DP 6: IBSE

Children plan and conduct their own investigations to prove that ice and steam both come from water

The children were asked to plan and conduct their own experiments to investigate the changing states of water. They were allowed to use any of the equipment in the room (school lab) and to go outside as well. Before the children could start their experiments, they had to document their plan by writing down or drawing their ideas and procedures on a prepared "Scientist's sheet".

Children draw their plans and assumption on their "Scientist Sheets":
1. How does ice become water?
2. How does water become steam?

Children apply different sorts of heat to make the ice melt.

Figure 7: An example of a template

The curriculum design research model in Figure 8 depicts the different phases – analytical, prototypical and assessment– of the curriculum design research process, as well as the ways in which the project's research work and findings contributed to these.

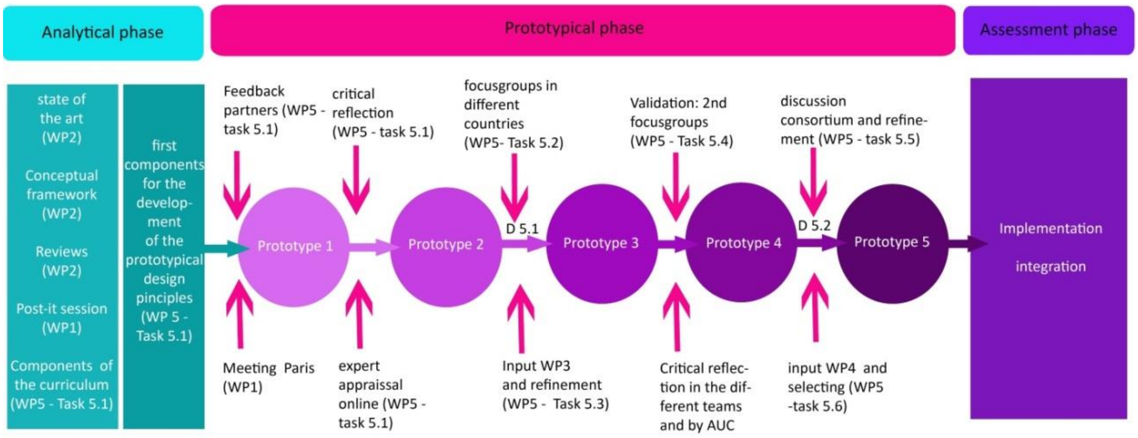

Figure 8: Curriculum design research model of Creative Little Scientists

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Key Findings

RQ1. Conceptualisations of teaching, learning and assessment of science and mathematics in Early Years by teachers (and in policy) in the partner countries. The role of creativity in these.

The explicit curriculum *rationale* for science education in nearly all partner countries was focused on children's role as citizens and highlighted science and environmental awareness as a part of their life in general; this was also reflected in what teachers said. However the research findings revealed that teachers' viewpoints regarding the rationale for science learning was in practice more holistic than what had been found in the policy documents in the partner countries. Learning *aims and objectives* were conceptualised by teachers as primarily contributing towards affective and social aspects of learning, such as increasing interest and positive attitudes towards science and science learning. These views contrasted with the emphasis in official policy documents on the development of knowledge and understanding of science and mathematics ideas and on process skills associated with scientific inquiry, especially in primary education.

In terms of *learning activities*, specific features of inquiry were conceptualised in both teachers' views and through policy guidance. Teachers in the preschool and early primary science and mathematics classroom made reference to inquiry based learning, a key part of the policy framing in all countries, in particularly through learning activities associated with observation, questioning, communication and the use of simple tools, which all took a dominant place among inquiry related activities. Yet, despite this general conceptualization of inquiry based learning, teachers' responses in fact rarely referred to inquiry activities related to practical investigations and using data to construct explanations.

In terms of conceptualisations about *pedagogy* teachers across the partner countries consistently and uniformly held a great appreciation for all valued pedagogical approaches that promote *dialogue and collaboration* in science amongst children, although teachers often failed to see the potential of these approaches for the development of creativity in children. This was consistent with policy which put some emphasis on their importance but included very limited reference to features of creativity that might be fostered through dialogue and collaboration and very limited guidance to support teachers in enabling creativity using classroom discussions and collaborative work.

There was an uneven treatment in both policy and reported practice of the approaches grouped in relation to the synergy *motivation and affect*. Learning approaches which are based on *building on children's prior experiences* or *relating science and mathematics to everyday life* were amongst those reported as most frequently used by

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teachers and referenced in policy, although these were not highlighted as 'creativity enabling' either by teachers or by policy documents. In addition, approaches making use of *drama* or *history to teach science and mathematics* were promoted the least frequently both by teachers and in curricula, which also failed to make reference to their potential for creativity.

There was a similarly uneven treatment of approaches with reference to the synergy *play and exploration*. Preschool teachers reported using open forms of *play* and *role play* significantly more than early primary school teachers, and a greater proportion of preschool teachers also conceptualised these as 'creativity enabling'. This was also reflected in preschool curricula across the partner countries with policy in the majority of them promoting *playful exploration* in preschool considerably more than in primary education. On the other hand teachers and policies of both phases were in agreement in fostering children's *physical exploration of materials*, an approach also conceptualised as 'creativity enabling' by teachers and in policy, and especially for primary education.

Teachers, as well as policy guidance, emphasised teaching approaches linked to *problem solving and agency* across both phases of early years education. These approaches were also often suggested to foster children's creativity, particularly in preschool.

Learning approaches associated with *questioning and curiosity* and their importance in fostering creativity were similarly conceptualised by teachers and in policy guidance. Practices that encourage children to ask questions and foster their imagination were reported as frequently used by teachers, were emphasised in policy and were perceived by both as 'creativity enabling'. In contrast, the role of teacher questioning and the value of varied approaches to children recording their ideas in supporting creative learning were given more limited recognition.

Learning approaches linked to fostering *reflection and reasoning* were perceived to have limited scope in promoting children's creativity by both teachers and in policy documents, though teachers reported using them quite or very frequently.

In terms of teachers' conceptualisations about *scaffolding*, teachers saw themselves as facilitators of children's own inquiry, delaying instruction until the learner had had a chance to investigate and inquire on their own or with others. They were a little more reticent to allow children to find solutions on their own, although they strongly rejected the suggestion that they should first act as demonstrators of the correct solution before children investigate for themselves.

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Episode 'Forest School' (3-5 years old) (Scotland):
Observing changes in the natural environment over time

In this setting visits to a local wildlife area are planned each week to provide children with opportunities to explore the natural environment and observe change over time for example in the weather and in the life cycles of living things. Visits are also designed to foster *children's own interests and explorations* and to encourage a range of inquiry skills in particular *observing* and exploring, *asking questions*, developing skills associated with *reasoning and making connections*.

The school organises clothing and resources carefully to enable visits in all weathers, such as mats, blankets, thermal clothing, warm drinks and snacks. A variety of equipment is taken to support activities at the site, including tarpaulin and ropes for making a shelter, magnifiers, binoculars and a camera to support observations, collecting pots, litter pickers and spades.

The explorations of one child, Ian, illustrate the opportunities to foster creative dispositions in particular *motivation*, *curiosity* and *sense of initiative* in his active pursuit of his own interests and observations. First he spent a long time at the pond that was covered with ice. He noticed bubbles and began breaking up the ice *'so they (the frogs) can breathe'*. A second focus of activity was taking photographs of the different fungi on the site to add to his growing collection.

In reflecting on his visit later in the day Ian highlighted these two activities (breaking ice and photographing fungi), making connections with previous visits. *'I think I saw frogs in the summer – and before I saw frogspawn.... It was sort of jelly – and tadpoles inside the ball of jelly.... Not the kind of jelly from what you eat and got tadpoles inside it'.*

Assessment, especially formative assessment, was widely highlighted as an important area for development in both policy and practice in both preschool and primary phases. However, policy guidance in terms of both methods of assessment and criteria for assessing on-going progress was often found lacking which is reflected in considerable variability in assessment approaches found across partner countries.

A common tendency to focus on *product* instead of *process* in assessment, allied with the pressures of statutory summative assessment processes in a number of partner countries revealed a number of challenges related to assessment of inquiry and creativity. Whilst the *assessment* of science and mathematics was widely emphasised in policy, more limited attention was given to assessment of inquiry processes and procedural understanding, and even less to social and affective dimensions of learning across the majority of partner countries, even though these dimensions were often

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highlighted in the *rationale* and *aims* set out for early science and mathematics education. Teachers' responses to the survey regarding their priorities for science *assessment* on the other hand were consistent with the frequency with which they indicated pursuing the corresponding *aims and objectives* in their science teaching.

Finally, there was very limited evidence in policy of a role for creativity either in the priorities or methods for assessment advocated. In particular, little attention was paid to multimodal forms of assessment or the involvement of children in assessment processes often associated with creative approaches to learning and teaching in the early years. Again here a contrast was noted between findings from the policy and teacher surveys as teachers reported taking account of children's multimodal expressions for assessment purposes, especially in preschool.

Episode 'Minibeasts' (6-7 years old) (Malta):
Observing and making connections to previous experience

The teacher allowed the children space and time to work freely in groups and explore their environment as they saw fit. This freedom resulted in the children engaging in discussions where they were spontaneously questioning and discussing their surroundings.

The children observed different minibeasts and were very interested, engaged and motivated to record and discuss their observations.

They demonstated creative dispositions in their *curiosity*, in raising their own questions and in *making connections* with previous experiences:

C₁: *See what this is…*

C₂: *That is a pupa…it was a caterpillar once.*

C₁: *Yes we had one in our garden…it turns into a butterfly.*

C₂: *Look how it is stuck to the tree. Will it fall?*

C₁: *How long do they take to become a butterfly?*

RQ2. Approaches used in the teaching, learning and assessment of science and mathematics in early years: opportunities for inquiry and creativity.

Findings indicated considerable potential for inquiry and creativity in the opportunities teachers provided for the *generation and evaluation of ideas and strategies* in both preschool and primary settings. Opportunities for the generation *of ideas*, for example, were fostered by rich motivating contexts for play and

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exploration, whilst purposes for inquiry were linked to children's everyday experiences and there was considerable scope for children's decision making.

Dialogue and collaboration, promoted by widespread use of group work and teacher questioning, played important roles in encouraging the processes of reflection and explanation associated with the *evaluation of ideas and strategies*.

The potential of sensitive and responsive teacher scaffolding both to support independence and extend inquiry was underlined, particularly in relation to when to intervene and when to stand back in order to listen to and build upon children's creative engagement and the development of their ideas and questions.

Episode 'Magnetic Attraction or Not' (3-4 and 5-6 year olds) (France): developing a collective conceptualization through exploration and dialogue

The children explored whether objects were attracted to a magnet or not. The objects included pairs of scissors that were made out of iron and plastic, so part of the scissors were magnetic and part of them were not magnetic. The children tested the materials and *generated their own categorisations* in small groups. They then came together to form and record *a collective categorization as a whole group*. The category in which to place the scissors posed a problem for the class as different results for the scissors had been recorded depending on which part of the scissors had been tested with the magnet. At the end of the workshop a girl showed creativity in *offering a solution* to the problem by suggesting that the scissors could be placed 'on the line' between both categories, *fostering new understanding* that an object might belong in more than one category linked to the different materials from which it is made.

Opportunities for play were limited in primary settings. The value of play and exploration in the primary age phase could be more widely appreciated, for example in generating ideas and questions and fostering a feel for phenomena.

Findings suggested that the roles of varied forms of representation and the *processes* of representation (not just the product) in developing children's thinking needed greater recognition, this included the role of ICT, particularly in preschool settings.

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Assessment approaches observed were generally informal and formative and were based on observation and teacher questioning. There was limited evidence of the involvement of children in assessment, although interviews with children during fieldwork did indicate their capabilities to reflect on their learning and gave new insights into learning processes.

There were few examples of episodes involving the use of outdoor resources or non-formal settings for learning in museums or the wider community. Here differences were noted between preschool and primary settings. In a number of preschool settings, children had free access to outdoor areas, and the overall provision of space and staffing levels were more generous providing greater scope for practical exploration.

The aims of activities were often implicit. Where aims were made explicit, they rarely included an explicit focus on creativity although the promotion of creative dispositions was evident in the majority of episodes observed. In both preschool and primary settings there was a strong focus on social and affective factors of learning and the development of scientific and mathematical concepts and process skills was a common feature of episodes observed. Explicit focus on the nature of science was limited.

**Episode 'Measuring Outside' (6 years old) (Finland):
Trying to find something a big as the stick**

The children spent time in the forest with the teacher and observed the environment. The aim was to capitalise on opportunities for measuring. They measured the heights of different plants and made comparisons for example using the concepts smaller, bigger and equal. They also measured the temperature on and inside the snow, as well as the temperature of water.

The teacher then presented a challenge *"try to find a plant that is smaller than yourself"*. This activity provided opportunities for *problem solving and agency*, and children *generated their own creative solutions*. One child for example added some snow in order to 'make' a plant of the correct height. Children were asked to explain and justify their solutions. This provided opportunities for the creative use of *reasoning skills* in evaluation.

Findings underlined the important influence of teachers' wider perspectives on learning and teaching, and their views of the nature of science and mathematics and understanding of creativity on the aims and approaches explicit or implicit in the activities observed. Teachers in most settings designed their own learning experiences

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with only a small proportion of episodes relying on textbooks or published schemes, where this was observed it was most common in the teaching of mathematics

Partners commented on the greater scope for child-initiated activity and creative engagement in preschool settings, although this was not always recognised by teachers, and on the tendency for pressures of time and curriculum requirements to limit opportunities for children's creativity and inquiry in primary settings.

RQ3. Ways in which these approaches seek to foster young children's learning, interest and motivation in science and mathematics

Across the episodes there were many examples of children *observing* and *making connections*, for example drawing on prior learning or between experiences. Opportunities for children's *questioning* were also present but not always recognised or built upon.

There was greater evidence of children's engagement in the social dimensions of inquiry, *explaining evidence* and *communicating explanations* than might have been expected from the findings of policy and teacher surveys; this was often prompted by dialogue with peers and adults.

Episode 'Making Musical Instruments' (4-5 years old) (Wales): Resources that support children's inquiry

The children were provided with a variety of resources to make instruments. The activity fostered creative dispositions in a number of ways. For example children were motivated to make musical instruments in a *different* ways. They showed *curiosity* in exploring the sounds made by their instruments and how they could be changed, *making connections* between the sounds made and their actions. For example one girl developed her own systematic investigation. She calmly, carefully and in a very considered way put dried peas one by one into her pot. Every time she added a pea she shook the pot, considered the noise and added one more. She continued for some time. Implicit in her actions was the question '*what happens* to the sound *if* I add another pea?', and an exploration of *relationships* between the number of peas and the sound produced.

Explicit examples of children's developing *understanding of the nature of science* were limited however starting points for the development of understanding of the nature of science was indicated in a number of episodes, in children's reflections on learning in classroom discussion or in interviews with researchers.

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Children's inquiry skills and understandings noted in episodes were interconnected with evidence of a number of creative attributes. For example children's *motivation, curiosity* and *abilities to come up with something new* were evidenced in raising questions and in their active pursuit of explorations and investigations. The episodes reported offered many examples of children's *sense of initiative* and *growing abilities to collaborate* in deciding what to do in carrying out investigations. Children showed *imagination, ability to make connections and thinking skills* in offering explanations.

How do teachers perceive their role in doing so?

Teachers involved in the case studies often indicated that they had not previously thought about the approaches they adopted in terms of opportunities for inquiry and creativity. Fieldwork processes had prompted reflection on the nature of inquiry and creativity in early mathematics and science and how this might be fostered.

Most teachers made reference to the importance of encouraging and supporting young children's engagement in early years science and mathematics as an important starting point for learning. Many emphasised the need to foster motivation and collaboration and provide a rich environment with space and time for exploration and problem-based learning, underlining key roles for teachers in encouraging reflection and making connections to promote children's conceptual understanding and the application of ideas in varied settings.

In sharing their approaches limited explicit reference was made to the role of creativity or to features of inquiry in science and mathematics.

RQ4. How can findings emerging from analysis in relation to questions 1-3 inform the development of practice in the classroom and in teacher education (ITE and CPD)?

Findings suggested a number of areas for attention in teacher education to support inquiry and creativity in early science and mathematics education. They included:

- Perspectives on the nature of science and mathematics and the purposes of science and mathematics education in the early years.
- The characteristics and roles of creativity in learning and teaching in early mathematics and science.
- Use of the outdoor and wider school environment for learning in science and mathematics.
- Approaches to planning at whole school and class levels to maximize scope and flexibility to foster children's inquiries and to provide opportunities for play and exploration (across both preschool and primary phases of education).
- Ways in which everyday learning activities can be opened up to allow space for children's agency and creativity.

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- The roles of questioning in supporting inquiry and creativity, different forms of teacher questioning, ways of supporting children's questioning, recognising questions implicit in children's explorations.
- Importance and roles of varied forms of representation, including the use of ICT, in supporting children's learning processes.
- Assessment strategies and forms of evidence that can be used to support learning and teaching in early science and mathematics, the roles of peer and self-assessment.

Fieldwork provided classroom examples for use in teacher education programs to illustrate and discuss the potential for creativity and inquiry within everyday classroom practices in early science and mathematics.

Implications and directions for future research

Findings from the project contribute new insights into the opportunities for inquiry and creativity in policy and practice in early years science and mathematics education.

The policy and teacher surveys conducted across the varied contexts in the partnership, indicate potential for inquiry and creativity, shown for example in common emphases on the importance of play, exploration and investigation and the promotion of curiosity or thinking skills in policy and in the priority given by teachers to the importance of social and affective factors in learning. However whilst policy in many of the partner countries advocates inquiry-based approaches, there are relatively few explicit references to creativity in learning within policy documentation. Though creative dispositions (e.g. curiosity or thinking skills) are mentioned, these are not framed within overt aims to foster creativity in teaching and learning. In addition although in some instances general references to creativity and inquiry are expressed in policy, these are often not reflected in specific curriculum or assessment requirements. This provides arguably conflicting and incoherent support for teachers and schools. Furthermore the emphasis is generally on the *generation* of ideas with more limited indications of scope for creativity in the *evaluation* and development of ideas and strategies or of ways in which children's involvement in assessment might contribute to these processes of evaluation.

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Episode 'Sun distance' (5 years old) (Portugal):
Developing understanding of the relative sizes of the Earth and Sun and the distance between them

The teacher planned a range of creative activities to foster children's understanding of the relative sizes of the Sun and the Earth and the distances between them, *providing a variety of materials* to represent the Sun and the Earth and the distance between them, giving them *time* to *raise questions* and *offer ideas and explanations*. For example the teacher set the problem: *"If the Sun is represented by a ball what would the Earth's size be and what would be the distance between them?"* The children showed imagination in suggesting that the Earth could be represented by a grain and that 'people would be the size of microbes' *making connections* with prior knowledge.

The children were asked to use their hands to show the diameter of the ball (the Sun) and asked how many diameters would represent the distance between the Sun and the Earth. When the children learned that it would take around a hundred, they were fascinated. The teacher then gave the children one hundred pieces of paper, each roughly the length of the diameter, to model the distance between the Sun and the Earth out in the corridor.

Through their own observations, the children noticed that the grain, which they had chosen to represent the Earth, could no longer be seen from the position of the ball, which represented the Sun. Subsequently, they *reasoned* that the distance between the Sun and the Earth was too great and the size of the Earth too small for it to be seen from the Sun. Children's *curiosity* was stimulated, they brought books about the theme, they talked with their parents and *raised more questions*. For example they brought in drawings where they tried to answer their own question *"How did Copernicus find out that the Earth that moves around the Sun?"*

The episodes reported in the Country Reports of fieldwork provide rich evidence of children's capacities for inquiry and creativity. They illustrate features of pedagogy related to the *synergies* between inquiry-based and creative approaches identified in the Conceptual Framework, for example through an emphasis on motivation and affect, reflection and reasoning, opportunities for problem solving and agency and the encouragement of dialogue and collaboration. Episodes also indicate the potential for sensitive scaffolding through teachers standing back to watch and listen attentively as well as to intervene to extend children's understanding in diverse ways. However findings from across the partnership suggest areas for further development and examination for example in relation to the more limited opportunities for play and for questioning reported in primary settings. It would be valuable to exemplify ways of creating such opportunities in the primary age phase within the greater constraints of

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time and curriculum requirements. Finally experiences during fieldwork in a number of settings highlighted the value of sharing fieldwork processes and outcomes with participants and the potential for the use of project findings to enhance recognition of opportunities for inquiry and creativity. This provided important feedback to inform development of the teacher training materials.

Findings suggest a number of implications for future research, particularly in relation to factors that were not strongly represented in the data such as:

- Opportunities for outdoor learning in the wider school environment
- The potential of children's use of ICT to enhance inquiry and creativity
- Role of representation in varied modes in fostering young children's reflection and reasoning
- Opportunities for exploring the nature of science with young children

Or aspects of practice that it was more difficult to observe with the limitations of staffing and time including:

- Role of free flow play in fostering inquiry and creativity over time
- Contribution of informal and non-formal approaches to young children's learning in science and mathematics
- The contribution of peer and self-assessment to the development of creative dispositions in early science and mathematics.

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