CREATIVE LITTLE SCIENTISTS:
Enabling Creativity through Science and Mathematics in Preschool and First Years of Primary Education

D2.2 Conceptual Framework

ADDENDUM 1 of 4:

Literature Review of Science and Mathematics Education

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A. Introduction

A1. Aims of this paper

This paper contributes to this work package by providing a review of science and mathematics education for children up to the age of 8, exploring links between mathematics and science education and links with creativity in education. The proposed framework for this review is designed to address key aims of the work package. In particular, providing a basis for:

- Identifying links between science and mathematics and their relation to prominent early learning themes including curiosity and inquiry, and creativity;
- Identifying links between certain teaching and learning approaches, and creativity;
- Definitions and aspects of creativity and related concepts in science and mathematics education.

Providing a comprehensive review of the literature in this field is beyond the scope of this review. Rather, the paper focuses upon significant developments in our understanding of science and mathematics education and early learning, and draws attention to those deemed most relevant with respect to opportunities for creativity in science and mathematics education.

A2. Methodology of review

A2.1 Coordinating literature searches

Materials provided by nine consortium partners informed this review (from institutions in Belgium, Finland, France, Germany, Greece, Malta, Portugal, Romania, and the UK). To coordinate literature searches, a template was provided indicating broad themes within the remit of this review, and each partner was asked to identify areas with which they were most familiar. By using this completed template (Appendix A) to address any areas not covered, this process supported the authors in their aim of ensuring a more representative literature review.

A2.2 Gathering materials

Materials were gathered predominately through on-line searches, (using a range of databases, including Google Scholar) focusing upon formal literature (peer-reviewed journal articles and policy documentation) pertaining to children in the early years. Early years is defined here as children aged from birth to eight, thereby capturing the age in which children across all European Countries make the transition into formal schooling. As well as drawing upon familiar literature, materials were found through searches using keywords such as 'early years, children, primary, elementary, science, mathematics, education, creativity', then further investigating work citing or being cited by these materials.

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Papers identified by partners using this open strategy were recorded in a single bibliography. Given the time constraints of reading and reviewing all papers, partners were further asked to complete a rubric for research papers (Appendix B) and key policy papers (Appendix C) considered the most significant for this review. Finally, partners were also asked to complete a further rubric (Appendix D) to provide more detail in regard to certain aspects of their national policy in science and mathematics in the early years: this often required completion of two documents to cover children from 0-8.

A2.3 Feedback process

As a first step references from the rubrics were linked to themes in the template proposed for the review. This suggested areas where further search of the literature would be needed. An initial document structure was then created drawing upon references from the rubrics and the wider the bibliography. All partners in this work package reviewed this document. Feedback helped identify any unaddressed areas but more significantly, particular themes that could be highlighted for this final deliverable.

A3. Structure of this document

The review begins by providing a context for this project, identifying key changing perspectives in mathematics and science education as well as of young children. The paper then examines recent literature (predominately 1990 onwards) relating to the children's learning and pedagogy in science and mathematics. The themes emerging from his review are then used to inform an initial review of policy documentation from partner countries in this field. The final section provides a list of key themes emerging from this paper and implications for subsequent work packages in this project.

B. Changing perspectives on science and mathematics education and young children: Potential for creativity

In trying to identify significant developments in our understanding of children's learning in science and mathematics, it is important to start by highlighting changing perspectives on the aims of science and mathematics education and of young children themselves. These perspectives will very much influence how we evaluate different pedagogical approaches. This section summarises some of the recent developments in policy and research that are relevant to how we perceive science and mathematics education for young children and why these changes indicate a significant role for creativity.

B1. Rationale for science and mathematics education

B1.1. Economic climate

Two key factors have increased the demands for a technically skilled workforce in Europe: globalisation, and evidence of a younger generation's

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decreasing interest in science and technology education. It becomes clear from official European Union's documentation that an adequate supply of scientists is considered crucial for a knowledge-based economy (European Commission, 2006). A primary objective therefore is to increase motivation, foster positive attitudes, for sciences in education (Feng, 1987; Fensham and Harlen, 1999; Millar and Osborne, 1998). According to Gago (2004), this need to motivate students has led to increased attention to the cultural, historical and philosophical aspects of science and technology in an attempt to portray these as human activities. This increased attention may enhance the appeal of these subjects to those pupils who are searching for some 'meaning' to their studies, rather than the acquisition of factual information and established, orthodox explanations of natural phenomena.

In order to compete globally, it is further argued it is important that individuals develop the skills and confidence to apply their knowledge in innovative ways. Indeed the European Commission suggest that entrepreneurship has to be taught during the education years in order to acquire skills to start and run a business (European Commission, 2007).

B1.2 Competencies for citizens

There is a growing recognition within the science education community that scientific literacy plays an increasingly important role for 21st Century society, not just for individuals (Harlen, 2008). Looking at the world from a scientific perspective enriches the understanding and interaction with phenomena in nature and technology, enables students (and therefore future adults) to take part in societal discussions and decision-making processes, and gives them an additional element from which to form interests and attitudes.

In Europe, scientific and mathematical competence is viewed as a dimension of democratic citizenship, as far as an informed citizen can better contribute to the decisions of the community to which she/he belongs (European Commission, 2007). Zohar (2007) discusses how high quality scientific thinking is one of the key goals in 21st century schooling: a good thinking capacity is a prerequisite to be a critical citizen in a democratic society and a necessary condition when facing such vast quantities of information and in using new technologies.

It becomes clear therefore the aim of science and mathematics education is not simply to create future experts in this field. Indeed, one key point emerging from the report *Beyond 2000: Science education for the Future* (Millar and Osborne, 1998) is that we can no longer continue to offer a science education whose primary function is a pre-professional preparation for future scientists. Rather, it is important also to teach young people something about science – commonly termed 'ideas-about-science' – as well as developing an understanding of the major concepts of science. This is reflected in the European Commission report (2007) which identifies 'mathematical competence and basic competences in science and technology' as key attributes needed by individuals for personal fulfilment and development, active citizenship, social inclusion and employment.

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It is also important to recognise the growing public attention to science related issues in society (Duit and Treagust, 2003; Hodson, 2003). Current issues include global warming, genetic engineering or eco-fuels. Indeed, in countries such as Finland, there is a close link between science and environmental studies that address these contemporary, socio-scientific issues. This highlights the point made previously that there is growing recognition that scientific literacy is needed to take an active part in debate over topical issues.

In contrast to science, mathematics might be considered more abstract and less prominent in public debates. Yet, mathematics plays a significant role in comprehending major issues, ranging from current financial crises to the common reporting of population surveys.

B1.3 Aims for science and mathematics education

In science and mathematics it is possible to consider both knowledge, and the processes involved in gaining that knowledge: 'content and process'. In this regard, we can identify a number of ongoing tensions concerning the relationship between these two aspects, and their relative importance for learning. Such tensions often spill out in political debates, for example in the UK where there have been recent calls for a returning focus on learning facts[1].

The dynamic inter-relationship between 'content and process' is significant in both science, and mathematics education. In science, there has been increasing recognition of the importance of developing pupils' understanding of the 'nature of science' and 'procedural understanding' (Duschl, Schweingruber, and Shouse, 2007; Eady, 2008; Harlen and Qualter, 2004; Kallery, Psillos, and Tselfes, 2009). According to Gago (2004, p.138) "Understanding the 'nature of science' has become an important concern in the curriculum. This often means the rejection of the stereotypical and false image of science as a simple search for objective and final truths based on unproblematic observations. The recent emphasis on understanding the nature of science is related to the attempt to give more attention to its social, cultural and human aspects. Science is now to be presented as knowledge that is built on evidence as well as upon arguments deployed in a creative search for meaning and explanation'. 'Procedural understanding' refers to an understanding of the processes in which science knowledge is acquired. The perceived importance of procedural knowledge is reflected in moves toward more inquiry based learning approaches that emphasise children's understanding and skills in finding out and evaluating information around them (European Commission, 2011).

Similar debates about content and process are echoed in mathematics education, however, it is important to acknowledge differences in terms and focus. In mathematics, a major tension that is discussed is between 'conceptual and procedural' knowledge. Procedural knowledge in this

1 http://www.guardian.co.uk/education/2011/jan/20/national-curriculum-review-facts-and-vital-knowledge

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context refers more to the skills in applying the right procedures to solve problems. This is contrasted with children's understanding of the concepts involved. However, it has been argued that this debate unfairly promotes conceptual understanding by taking a narrow, superficial view of procedural knowledge (Star, 2000). This tension is similar to that between 'instrumental and 'relational' knowledge discussed by Skemp (2006), where instrumental knowledge refers to the ability to carry out specific procedures or repeat certain facts, whilst relational knowledge is more concerned with understanding the significance of this information; how it relates to other ideas.

In contrast to science, the terminology 'nature of mathematics' has not gained the same currency. However, it is possible to draw parallels with debates around children's understanding of formalism in mathematics (e.g. formal symbols such as "7 + 6") and how this can seem disconnected from children's informal experiences. Arguably, mathematics requires particular effort to engage children in the nature of mathematics. Martin Hughes (1986) provides exemplar work addressing this challenge. Hughes carried out a range of studies that aimed to engage children in the value of numbers. This was approached by asking children to think of ways to mark jars to remember how many sweets were inside.

It is likely that certain dichotomies such as 'content v process, or 'concept v procedure' obfuscate the iterative relationship between the two. Greater procedural knowledge may be informed by, and in turn inform, conceptual understanding (Rittle-Johnson, Siegler, and Alibali, 1999); knowledge of content can provide the context for developing process skills, which in turn can help learners develop further concepts (Harlen and Qualter, 2004). In other words, rather than attempt to evaluate their relative importance, it is more productive to consider their interdependence and how the relationship plays out in learning. Greater understanding of such relationships should help resolve certain tensions and indicate ways to move forward in how we approach teaching and learning.

Whilst aspects such as concepts and procedures seem cognitive in nature, there has been concern that current science and mathematics education do not focus sufficiently on the role of emotive factors, such as children's attitudes and motivation. These factors help engage children in the classroom community and in critical processes such as asking questions or reflecting on thinking (Brown and Campione, 1994; Duschl et al., 2007). Emotional aspects are not just important in retaining children in science education (a significant concern indicated previously) but in supporting the learning process itself as outlined further below.

B1.4 Theories of cognition

Piaget's (Piaget, 1952; 1969) work was significant in profiling a child centred view of learning, although criticised for not recognising more experiential, social and affective processes. In this regard, Vygotsky (1978) has played a fundamental role in drawing attention to the role of language and tools in developing higher order thinking processes. Whilst there has

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been a growing recognition of the importance of affective factors, these have arguably been considered in terms of their effect on cognition rather than as an integrated part. Similarly, whist children's interaction with the world is understood as the foundation of learning, cognition is articulated as a gradual move toward less concrete and more abstract thinking (Bruner, 1971; Karmiloff-Smith, 1994; Piaget and Inhelder, 1969). These views of cognition are being challenged. Embodiment theories argue that it is not possible to separate thinking from perceptual and emotional experiences (Clark, 1999; Dourish, 2004; Lakoff and Núñez, 2000) (Barsalou, Simmons, Barbey and Wilson, 2003; Lakoff and Núñez, 2000).

According to Wilson (2002), it is possible to identify a number of claims made under the banner of Embodied Cognition, with some more controversial than others. Her paper distinguishes six claims: (1) cognition is situated; (2) cognition is time-pressured; (3) we off-load cognitive work onto the environment; (4) the environment is part of the cognitive system; (5) cognition is for action; (6) off-line cognition is body based. According to Wilson, this last claim may be the most powerful as it proposes that our thinking is grounded in mechanisms that evolved for interaction with the environment, even when we are not actually immersed in that environment. In other words, our concepts cannot be separated from prior sensory and motor experiences.

Although not without critics (Mahon and Caramazza, 2008), the Embodied Cognition viewpoint therefore places great emphasis on experiences in different contexts, both in our thinking whilst interacting within a particular context ('on-line') as well as thinking away from that context ('off-line'). Embodied Cognition therefore captures other theoretical developments such as Distributed Cognition (Hutchins and Lintern, 1995), or Situated Cognition (Lave and Wenger, 1991) that also move cognition away from the abstract individual mind.

These theoretical developments therefore have significant implications for how we perceive young children's learning in science and mathematics by reconsidering the role of children's physical, social and affective experiences when learning (Duit and Treagust, 2003). Rather than consider learning in terms of developing more abstract thinking, it may be more productive to understanding thinking in terms of its relation to different contexts. Significantly, the great limitations of trying to capture children's thinking through traditional static media, such as paper, become clearer. Instead, it is necessary to adopt a multi-modal approach, focusing on the wide range of ways that children express their embodied thinking (Glauert, 2009a); for example through their physical interactions, gestures and speech. Indeed, recent work has highlighted how children use gesture to support cognition (Goldin-Meadow, Nusbaum, Kelly, and Wagner, 2001) and are often able to express their understanding of certain concepts through modes such as gestures before speech (Goldin-Meadow, 2009).

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B1.5 Assessment practice

It is often argued that assessment practice drives teaching and learning (Black, 2001). It is therefore important to consider the climate of assessment practice. As well as changes to statutory summative assessments, there are ongoing arguments that current assessments are limited in capturing many aspects of learning such as thinking skills (Black and Wiliam, 2006). Paper based assessments also limit what type of information can be captured. For this reason, it is has been proposed that digital technology presents unique opportunities to not only capture a wider range of communication, but allow this information to revisited and shared with others as part of a more formative learning process.

B1.6 Developments in Technology

Digital technology does not only present new opportunities for assessing learning, but is shaping the actual learning process. There is growing rhetoric about how digital technologies are shaping new literacies. Indeed, the introduction of the calculator exemplifies how new devices can question fundamental practices in areas such as science and mathematics. Shaffer and Kaput (1998) argue that as mathematics cannot be separated from the tools we use, it is evolving with our 'virtual' culture. Not only can technologies help offload the demands of recording and calculating, but they are gradually removing the demands of collecting, organising and presenting data. Technologies to record and represent data is highly significant, as exemplified by recent projects looking at mobile devices to support personal inquiry (Anastopoulou et al., 2008), or tabletop computers to explore scientific concepts such as light (Price, Pontual, Sheridan, and Roussos, 2009).

As technologies play an increasing role in society, it is necessary to keep questioning their role in education: the extent to which children's ability to use the technologies forms an integral part of their learning. Tools such as video as well as improved ways to store, tag and share data, not only open up new opportunities for teaching and assessment but also of researching children's learning in context.

B1.7 Summary: The role of creativity

There are a range of factors therefore that are changing perceptions about the nature and role of science and mathematics education. Whilst these are complex, it is possible to identify certain themes: the need for more innovative thinkers, the need to increase positive attitudes, the importance of reasoning skills, and for learners to become more proficient in the procedures for acquiring new ideas. At the same time, we can see new opportunities occurring resulting from changes in ways we can express and assess thinking, emerging technologies and theoretical frameworks that underline how perceptual, social and emotional experiences cannot be separated from thinking.

These dynamics help explain the growing attention to the role of creativity in science (Barrow, 2010; Heller, 2007; Schmidt, 2010) and mathematics

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education (Barbeau, 1985; Worthington, 2005), as well as related concepts such as curiosity, wonder, context or emotion, (Ginsburg and Golbeck, 2004). This interest can be witnessed in both research literature and policy documentation; however, the processes through which creativity can be leveraged to support science and mathematics education remain arguably unclear.

It is also not clear the extent to which greater emphasis on the role of creativity is beneficial for children's science and mathematics education in the early years. Factors such as motivating learners to continue studying science, or becoming business entrepreneurs seem more removed. Yet, developments in our perspectives of young children raise the possibility that creativity may actually play a significant role.

B2. Perspectives on young children

B2.1 Democratic rights

Progressive pioneers including Pestallozi, Froebel, Montessori, Dewey and Langeveld as well as various school movements (e.g. Reggio Emilia, Steiner, Jenaplan, Freinet, Dalton, Freya Jansen, and Ferre Leavers), have emphasised the need for a child centred approach and the role of the child as a researcher. However, developmental and elementary traditions have tended to emphasise the incompetence/immaturity of the child in comparison with adults, and to focus on nurturing their future conceptions rather than help express their current ones. In contrast contributions of new sociologies of childhood place emphasis on children as active agents, citizens with rights, and the importance of children's voice. Rather than teach children science to support their future, there is greater focus on the importance of education in their lives now. This has led to increasing recognition of children's capacities to take ownership of their own learning, and take part, on a meaningful level, in democratic processes. Indeed, this is recognised in the UN Convention on the Rights of the Child that identifies rights not just to provision and protection, but to participation (Mayall, 2006).

B2.2 Early cognitive abilities

In the last couple of decades, new research methods have been able to uncover many early abilities. In mathematics, for example, it has been shown that children's innate perceptual process allow them to make correct estimations in addition and subtraction problems (Gilmore, McCarthy, and Spelke, 2007; Wynn, Bloom, and Chiang, 2002). As discussed previously, gestures research has also indicated children's earlier understandings of different ideas. In other words, by looking beyond children's verbal limitations, it has been possible to recognise their nascent understandings in range of ideas.

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B2.3 Impact of early educational experiences

It has become increasingly clear that young children's early educational experiences impact on later outcomes (Sylva, 2009), both in terms of educational achievement but also the attitudes towards subjects. Indeed, children's anxiety in mathematics is observable from the early years (Gifford, 2004). According to Gifford, anxiety may stem from overly directly approaches emphasising right and wrong responses. Consequently, a new mathematics pedagogy is proposed, based on holistic principles and considering children's mathematical learning in terms of cognitive, physical, social and emotional aspects.

Before children begin formal schooling, they have accrued a wealth of experiences of the world around them. Children have also received significant didactic interaction with caregivers (Nilholm and Säljö, 1996). It has become increasingly evident that children draw upon this experience in developing their more formal understandings. This notion is emphasised by recent embodiment theories previously discussed. As a result, it has been proposed that a key educational challenge concerns how to bridge children's informal and formal learning experiences (Canobi, 2007; Lind, 1998).

B3. Summary: Role for creativity in science and mathematics for the early years

Changing perspectives on young children therefore reflect a more positive attitude to their abilities and the potential to build upon these by developing methods to help children express their thinking and respecting their voice. It is also possible to see much overlap with previous themes surrounding changing perspectives in mathematics and science education, where there has been increasing recognition of the importance of fostering innovative thinking, personal meaning, positive attitudes, and tools through which children gain knowledge (rather than focus on knowledge per se). This overlap is reflected in six assertions by Eschach and Fried (2005) for why children would benefit from early exposure to science: '(1) Children naturally enjoy observing and thinking about nature; (2) Exposing students to science develops positive attitudes to science; (3) Early exposure to scientific phenomena leads to better understanding later in a more formal way; (4) The use of scientifically informed language at an early age influences the eventual development of scientific concepts; (5) Children can understand scientific concepts and reason scientifically; and (6) Science is an efficient means for developing scientific thinking' (Eshach and Fried, 2005, p.135).

Therefore, changing perspectives on science and mathematics and young children do seem to indicate a role for creativity in early science and mathematics education. However, in order to understand the potential for raising the profile of creativity, it is necessary to examine in closer detail the mechanisms through which children learn in science and mathematics.

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C. Early learning in science and mathematics before school

As previously emphasised, children develop many ideas in science and mathematics before they start school. This section draws out some significant developments in our understanding of children's pre-school abilities including as infants. These developments in our understanding are often the result of the development of new research methods.

C1. New methods: New insights

Changing perspectives on young children and on science and mathematics education affect the questions we ask when examining learning and what we consider valid data. It has become clear that it is inadequate simply to ask whether children can recall specific facts and procedures, as their ability to draw upon, negotiate with others, and adapt these ideas in different contexts will depend greatly upon their attitudes, meaning, and understanding of how this knowledge relates to other experiences. Similarly, it is problematic to require children to express their thinking in a particular way: e.g. writing, when their understanding and application of knowledge may be expressed differently. Infant studies, that use children's gaze to identify familiarity with stimuli (Wynn, 1992), or gesture analysis (Roth, 2000), exemplify the benefits of being sensitive to ways in which children demonstrate their thinking.

New methodological approaches have provided a richer account of children's abilities by considering children's expression of ideas through a wider range of modes e.g. gesture, actions, narratives, and importantly, respecting children's alternatives ideas, not just as simple 'misconceptions', but as rich sources of information about children's personal interpretations and personal meaning for different experiences. This approach attempts to capture the more dynamic nature of children's thinking methods (Fleer and Robbins, 2003; Metz, 2004). This more grounded approach reflects the use of more qualitative methods, using tools such as video to capture thinking and learning processes (Angelillo, Rogoff and Chavajay, 2007). Developing tools for analysing and reporting video data has strengthened this approach (Angelillo et al., 2007).

C2. Infant learning

C2.1 Core knowledge domains

Research in developmental psychology has revealed that children have core systems of representing: objects, actions, numbers, places, and social partners (Spelke and Kinzler, 2007), providing domain-specific competencies about naïve physics, biology, and psychology (Goswami and Bryant, 2007; Wellman and Gelman, 1998).

For naïve physics, for example, research has shown how infants can make predictions about novel events, demonstrating causal learning. In numerous experiments, Baillargeon (Baillargeon, 2004; Baillargeon, Li, Ng

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and Yuan, 2009) showed explanation-based learning in infants' physical reasoning about containment, support, occlusion and other events. Children's predictions about physical events have also been investigated in terms of the numerical ability. Children's ability to subitize: enumerate quantities up to around five without counting, allows them to make accurate predictions about small numerical changes, such as addition and subtraction of small amounts (Wynn et al., 2002). Work has recently attempted to identify whether such innate abilities are precursors to children's later numerical reasoning (Gilmore, et al., 2007).

Cognitive neuroscience studies suggest that when children learn particular scientific concepts, such as the Newtonian theory of motion, these concepts do not replace their prior naïve theories. Rather than undergoing conceptual change, the brain appears to maintain both theories. Selection of the correct basis for reasoning in a given situation then depends on effective inhibition – metacognitive strategies discussed later. This process of coordinating naïve and instructed theories is also relevant to mathematics where children may have difficulties in processing numerical transformations as continuous or discrete quantities, with the latter developed from counting and calculation instruction.

With respect to naïve psychology, infants' joint attention skills arise directly from their emerging understanding of other persons as intentional agents (Tomasello, 1995). Much work has focused on children's developing theory of mind, which refers to 'the capacity to interpret, predict, and explain the behaviour of others in terms of their understanding mental states' (Scholl and Leslie, 1999, p.132). Wellman and Lagattuta (2004) focused on the relationships between theory of mind, learning, and teaching. They argued that children's psychological explanations are central to formal school-based teaching and learning. According to the authors, 'psychological explanations are a frequent topic in many educational endeavours, but they also provide an important platform for logical-explanatory reasoning more broadly considered. Thus, encouraging children to provide explanations and to evaluate and comment on other's explanations is an important teaching method for engendering meaningful learning. To explain something is to make sense of it, to reason about its meaning, within one framework or another. Much teaching targets this meaningful level of learning and understanding—the objective is for students to understand the explanations and reasons for various phenomena and procedures' (p. 492).

C2.2 Reasoning

Goswami and Bryant (2007) identify four forms of infant learning mechanism: statistical learning (neural structures from patterns of observed events); learning by imitation; learning by analogy; and causal learning. Causal or 'explanation-based' learning is present in infancy; however, the ability to deal effectively with multiple causal variables – scientific reasoning – develops more slowly.

Scientific reasoning is usually understood as the kind of thinking that requires the co- ordination and differentiation of theories and evidence, and

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the evaluation of hypotheses (for example Kuhn, 1989). Research suggests that children as young as six understand the goal of testing a hypothesis, and can distinguish between conclusive and inconclusive tests of that hypothesis in simplified circumstances (e.g. Sodian, Zaitchik and Carey, 1991). It has also been shown that children have an earlier capacity to reason scientifically (Duschl et al., 2007; Eshach and Fried, 2005), but find this difficult in situations when they have to ignore their pre-existing knowledge and reason purely on the basis of the data, and when they have to keep multiple variables in mind at once (Kuhn et al. 1995). Given these barriers, it is interesting to reflect upon emerging theories of cognition that highlight the role of the environment in supporting cognition (such as helping keeping variables in mind).

C2.3 Metacognition and executive function

Metacognition is knowledge about cognition, encompassing factors such as knowing about your own information-processing skills, monitoring your own cognitive performance, and knowing about the demands made by different kinds of cognitive tasks. Executive function refers to gaining strategic control over your own mental processes, inhibiting certain thoughts or actions, and developing conscious control over your thoughts, feelings and behaviour (Goswami and Bryant, 2007).

Young children may be developing their metacognitive processes in the early years, presenting challenges for skills such as planning and strategy choice (Ellis and Siegler, 1997). However, naturalistic videos in classrooms have demonstrated children's capacity for these processes, such as awareness of strategies, in their talk (Coltman, 2006).

Developments in metacognition and executive function tend to be associated with language development, the development of working memory (which enables multiple perspectives to be held in mind) and nonverbal ability (Hughes, 1998). According to Schoenfeld (1987), there are three ways to talk about metacognition in mathematics: knowledge; self-awareness (self-regulation); and beliefs and intuitions, reinforcing the need to consider affective factors into account.

C3. Pre-school experiences

Children accumulate a wealth of experiences in informal contexts before they begin more formal learning contexts in school. These experiences foster children's motivation to understand their world, where conceptual change is better understood as an intentional activity with regard to the learner, simultaneous reconstruction of conceptual contexts, as well as increasing awareness of contexts for their application (Larsson and Halldén, 2010). From as young as two or three, children are able to make causal inferences about information they gain from the environment, demonstrating abilities to reason and reach conclusions, although not necessarily verbally (Gopnik, Sobel, Schulz and Glymour, 2001).

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C3.1 Play

Children will also differ in the nature of play experiences and interactions with materials before school. The role of play has been long-debated, a key difficulty being variations in how to define play. The importance of these early interactions between materials and 'more expert' others is articulated in major learning theories, stemming from the seminal work of Vygotsky (1978).

According to Goswami and Bryant (2007), thinking, reasoning and understanding can be enhanced by imaginative or pretend play, although, scaffolding by an adult is required if these are to be effective for learning in school. In this regard, play provides opportunities for parents to introduce children to certain ideas. van Oers (2010), for example, refers to parents being able to 'mathematicise' play by drawing children's attention to certain ideas.

Play also provides children with opportunities to develop their naïve theories about the behaviour of others. For example, socio-dramatic role-play helps children to gain insights into the beliefs, desires and intentions of other agents(Goswami and Bryant, 2007). Language is also important, as (for example) family discourse about emotions and their causes is linked to earlier development of 'theory of mind' (for example Dunn, Brown, Slomkowski, Tesla, and Youngblade, 1991).

C3.1.1 Materials

As well developing fine motor control skills (which have been linked to later cognitive measures (Piek, Dawson, Smith and Gasson, 2008), children's physical interactions will determine opportunities for exploring various causal relationships. Consequently, the richness of children's home environments is considered significant in their learning (Sylva, 2009). As well as simple physical materials, it is important to consider other materials in children's physical environment, ranging from their experiences with paper (e.g. drawing / reading) to their competence with a range of tools (e.g. scissors) that will support learning later in formal settings. As French (2004) argues, through practical experience with materials for example in 'mixing primary colours, creating shadows, trying to make a piece of clay float' (p140), children begin to develop expectations and understandings related to scientific phenomena and events in the world around them. In her examination of the SureStart curriculum project she underlines not only the importance of a rich environment with opportunities for child-led exploration but also the key roles of dialogue with adults in making sense of experiences.

It has also become increasingly important to consider the impact of digital technologies. Digital technologies have become ubiquitous in children's home environment and are gradually changing their early playful experiences. As a result, there has been public and research interest in the impact of early experiences with digital materials (Plowman and Stephen, 2005). As new forms of interaction with technology (e.g. iPad) allow children to interact at younger (pre-school) ages, a new market has opened

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up selling early learning applications. There are already over 1000 apps on the iPad tagged for toddlers (US terminology), many of which target basic school skills such as recognising numerals or basic calculation sums. The introduction of technology into young children's lives is not without controversy, with many public debates about the possible detrimental effect on children's learning (Economist, 2008; Guardian, 2011). There are interesting questions therefore surrounding the impact of these new technologies on children's more creative thinking.

C3.2 Role of caregivers

Children's early learning is socially mediated (Goswami and Bryant, 2007), where parents can provide extensive support in everyday settings for children's developing strategies for collecting and interpreting evidence and theory construction (Crowley, et al., 2001). Work has highlighted significant interactions, such as between mother and child, in children's problem solving skills (Nilholm and Säljö, 1996). In the home, children learn roles in dialogue that will impact their school experiences, such as their understanding of open-questioning (Harris and Williams, 2007). Children will also vary greatly in their familiarity with more specific domain vocabulary, for example, the term 'take away' may be more familiar in relation to food than a numerical operation.

C3.3 Link home to school

Given the depth of children's experiences before school, there are great opportunities to build upon the skills and understanding in school (Canobi, 2007). Unfortunately, the extent to which this occurs may often limit this potential: 'The mathematics that children bring to school should be valued and utilised in the classroom. Research points out that one of the difficulties in trying to improve the teaching of early mathematics is that teachers tend to underestimate the capabilities of young children when it comes to mathematics and may not have the knowledge to focus on important mathematical experiences' (Dawson, 2003).

Research is providing growing evidence of the opportunities for science learning offered by involvement in everyday household and family activities. Investigations of pre-school children's questions and parents' explanations in the home have highlighted ways in which routine events can prompt children's questions and causal (Callanan and Oakes, 1992). Studies have examined the impact of informal experiences on children's scientific knowledge, indicating for example the benefits of keeping pets (Inagaki, 1990; Prokop, Prokop, and Tunnicliffe, 2008). They suggest the contributions that everyday activities and conversations related to food (Cumming, 2003) or gardening (Ruby, Kenner, Jessel, Gregory and Arju, 2007) or concepts of health (Reeve and Bell, 2009) can make to fostering children's interests and learning.

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D. Early learning in science and mathematics in school

As the previous section highlighted, children meet science and Technology in many realms of life. But it is only at school that they are exposed to science in an organised and explicit form (Gago, 2004). This section considers some key themes in terms of children's learning of science and mathematics education in School.

D1. Science and mathematics proficiency

Duschl et al. (2007) identify four strands of science proficiency that are interwoven in learning and teaching:

- Know, use and interpret scientific explanations of the natural world
- Generate and evaluate scientific evidence and explanations
- Understand the nature and development of scientific knowledge
- Participate productively in scientific practices and discourse

As highlighted in earlier sections, the first two strands reflect the importance of children gaining an understanding of the explanatory models of science as well as the skills and knowledge associated with scientific procedures. Furthermore, it has become clearer that the two aspects are highly interconnected. Feasey (1994) makes this point by highlighting the close connections between processes and concepts in learning across a range of different kinds of classroom activity (basic skills, observations, illustrations, investigations). For example, investigative tasks are intended to support the development of procedural skills and understandings, but pupils' processes such as their predictions, identification of variables, interpretations will be dependent on their existing conceptual understandings. Or the success of illustrative tasks that focus on conceptual understanding will be dependent on the ways in which children make sense of observations.

In addition, children's experiences, both informal and those nurtured in the classroom provide them with 'data' with which to generate and evaluate different ideas. However, this requires understanding of the relationship between evidence and theory linked to the nature of science (the third strand), with which children have difficulties (Metz, 2004). According to Metz, children have a bias towards interpreting evidence in terms of their existing theories. Kuhn (1989) emphasises the crucial importance of metacognitive processes: reflective awareness and deliberate control of cognitive activities, in coordinating theory and evidence. This may explain younger children's difficulties as their metacognitive abilities are still developing; but also raises the possibility for the teacher to use strategies and the environment to support children's thinking. Metz (1998) also highlights the point that children will not develop scientific reasoning automatically from experience and suggests it is more productive to consider what children can do and understand given effective instruction.

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Opportunities for participation in scientific practices and discourse in the classroom community (the fourth strand) play an important role in developing children's understandings of scientific reasoning processes. In particular the processes of sharing, testing and evaluating ideas can foster an appreciation of scientific argumentation and explanation. The teacher has a key role here in promoting a supportive climate for debate, questioning, feedback and critical reflection.

D1.1 Alternative thinking

There is an emphasis therefore on children's generating and evaluating different evidence and explanations, helped by their existing knowledge and experiences. What may be less clear is the value of children generating and considering ideas that are not 'correct'. Unlike, other subjects, such as the arts, science and mathematics offer established facts and procedures for solving problems. However, as indicated at the start of this document, understanding the nature of science requires an understanding of the sources and justification for accepted knowledge and procedures. Scientific knowledge requires evaluating some ideas over others. In this regard, there may be great value in children generating and evaluating alternative ideas in order to reason and understand the meaning and value behind a particular idea.

It is possible to draw on a range of evidence for the benefits of encouraging children to explore alternative ideas and strategies. Siegler (1987), for example, highlighted the process in which children employ a range of strategies in mathematics problems. It was shown how children fluctuate between strategies, gradually being able to identify the more efficient. As a result, Siegler highlights the need to examine children's strategy choice over time and highlights the dangers of averaging children's strategies across cohorts or time. The flexible use of different strategies by more competent learners has been shown in a range of problems such as addition (Gray and Tall, 1994; Torbeyns, Verschaffel and Ghesquiere, 2002) or multiplication problems (Ainsworth, Wood and O'Malley, 1998).

This process of exploration and tending towards more efficient strategies has also been articulated in Martin and Schwartz's (2005) theory of Physically Distributed Learning. The authors demonstrated how children with nascent ideas in a domain are able to manipulate the environment (e.g. number blocks in a fraction problem) to explore different possibilities, interpreting alternatives to identify more effective strategies. One key theme from Martin and Schwartz's research is the importance of providing children with sufficient problem space (alternative options) to allow divergent thinking. Indeed, there is considerable literature about the benefits of divergent thinking (notably in relation to creativity). However, it is important to consider two significant aspects: firstly how children can derive different ideas – building on their own and others' experiences, and secondly, the importance of children evaluating alternative ideas. Studies of children's theory choice by Samarapungavan (1992) suggest they can use a range of criteria in evaluating theories, such as range of explanation,

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empirical and logical consistency and 'non-ad hocness' of explanation, although only older children (11 years in comparison to 7 years) showed a systematic preference for non-ad hoc theories over ad hoc ones.

D1.1.1 Innovation v Efficiency

Whilst highlighting the benefits of encouraging children to generate and evaluate alternative thinking, it is important to consider how this may detract from time spent practising / becoming familiar with specific strategies. Schwartz, Bransford and Sears (2005) refer to this as the trade off between 'innovation and efficiency'. The authors discuss the cognitive benefits of innovation; yet propose that 'optimal learning' is a balance between the two. However, as their work refers to learners of all ages, it is possible that the benefits of innovative thinking are more pronounced for young children for reasons discussed in this paper. Nevertheless, we do need to consider times when it may be preferable to focus young children's attention on certain ideas. As an example, how much time would we want children to consider other base systems other than ten when learning about numbers ?

In science education the value of children discussing and testing out different ideas has been recognised for example in the teaching approaches advocated by the Nuffield SPACE project (see for example, Osborne, Black, Smith and Meadows, 1991) or through the use of concept cartoons (Keogh and Naylor, 2000).This can help children to debate how different ideas might be justified, to evaluate the evidence supporting different perspectives and to consider the effectiveness of particular explanations in accounting for the observations and events they have encountered

However as Asoko (2002) and Esach and Fried (2005) suggest, many scientific concepts introduced in the curriculum across the primary years (rays of light, force) do not emerge in a simple way from everyday observation and experience. It will therefore also be important for teachers to introduce children explicitly to scientific ways of viewing the world, to provide opportunities for children to try these out and to examine how they can be used to explain phenomena and events. Such an approach may also help children to begin to appreciate the bases for scientific explanations and their explanatory power in their application to a wide range of situations

D2. Social factors

In school, children have the opportunity to approach science and mathematics problems with peers. Work has shown the benefits of collaborative work on children's learning (David Wood and O'Malley, 1996) where talking aloud gives children's opportunities to think aloud (Monaghan, 2010). Indeed, the very process of explaining thinking verbally can help consolidate ideas (Chi, De Leeuw, Chiu and Lavancher, 1994) and create opportunities for developing children's exploratory talk with others (Mercer, Wegerif, and Dawes, 1999).

The communication of ideas and ways of thinking to the class allows children to listen to alternative ideas and contrast their own way of

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thinking. Through collaborative activities, children gain access to a wider range of problem-solving strategies (Mercer and Littleton, 2007). This gaining of awareness promotes, in some, the need to restructure their ideas, in face of other more plausible and consensual ones that appear in the social context of the class (Varela, 2010).

The collaborative nature of learning has an important impact on children's individual thought: it makes them more attentive to their own thought and the thought of others; and it stimulates the need to clarify or modify their own thought, based on their peers' comments and reactions. Not only do they share their ideas with the others, but they also learn, by the action of others, to monitor and auto-regulate their own thought. Group work may therefore benefit processes such as children’s metacognition (Larkin, 2006; Littleton et al., 2005).

D2.1 Fostering collaboration

Group work has been promoted in many countries as a key component of elementary science. However, often little guidance is given as to how group work should be organised, and because previous research has seldom been conducted in authentic classrooms, its message is merely indicative (Howe, et al., 2007). Howe showed how extensive training in generic group skills led to significant impact on young children’s collaboration on knowledge (Howe et al., 2007).

One important theme has been that teacher intervention should stress monitoring and guidance rather than control (Blatchford, Baines, Rubie-Davies, Bassett and Chowne, 2006). Even without teacher guidance, children are able to construct an argument and aim to hear alternative view points from other children (Naylor, Keogh and Downing, 2007). However, children may benefit from support in collaborative reasoning skills, for example the ‘Thinking Together’ program demonstrated the potential to foster inclusive learning environments through increases in reasoning and inclusion of others’ perspectives (Littleton et al., 2005).

In order for collaboration to benefit all children, strategies may be needed to motivate more reluctant speakers. One approach to this challenge was the Puppets programme (Naylor, Keogh, Downing, Maloney and Simon, 2007). This programme used puppets as a stimulus for children to engage in conversations involving reasoning in primary science lessons. Data from the studies indicated that the puppets were able to: engage and motivate children, promote talk involving reasoning; were particularly effective with reluctant speakers; appeared to be effective across the whole primary age range; and even promoted significant changes in teachers’ professional practice. Puppets therefore present a method through which teachers might encourage children to voice their different ideas, since the puppet, unlike the teacher, can be perceived as less judgemental of the validity of children’s thinking.

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D3. Affective factors

Affective factors include a host of constructs, such as attitudes, values, beliefs, opinions, interests, and motivation. While the affective dimensions of science learning have long been recognised as important, they have received much less attention by researchers than have the cognitive dimensions. Reasons for this imbalance include the 'archetypal image of science itself', where reason is separated from feeling, and the 'long-standing cognitive tradition' of science education research (Alsop and Watts, 2003, p.1044). A contemporary view is that the 'affective dimension is not just a simple catalyst, but a necessary condition for learning to occur' (Perrier and Nsengiyumva, 2003, p.1124).

D3.1 Attitude and motivation

Attitude and motivation are often discussed as the most critically important constructs of the affective domain in science education (Koballa and Glynn, 2008). According to Feng (1987), early science has three interrelated aspects: content, process, and attitude. Attitude involves the development of a scientific attitude that includes openness and objectivity. According to Gago (2004, p.125) "Important factors that have been shown to influence motivation in empirical studies are the students' perception of autonomy (Can I take some decisions myself?), of their own competence (Will I be successful, can I do this?) and of their being socially embedded within a (peer) group of people (Will I get help? Will my friends admire or condemn what I can do?). In addition, motivation depends on more school-related factors, such as the perceived relevance of the topic, the quality of instruction, or the interest of the teacher.

Attitude outcomes are of a different form than outcomes for skills and knowledge; they are exhibited in a different way, and they have deeper roots in the experiences that students bring to school. Attitude development is a lifelong process that involves the home, the school, the community and society at large. Attitudes are best shown, not by the events of a particular moment, but by the pattern of behaviours over time. Development of positive attitudes plays an important role in students' growth by interacting with their intellectual development and creating a readiness for responsible application of what is learned (Alberta Learning, 2004). Indeed, Goswami and Bryant (2007) highlight the importance of motivation in that the emotional system can modulate sensory processing, for example via attentional processes.

It has become increasingly clear therefore that it is difficult to separate affective factors from other learning processes. This supports embodiment theories that describe the interrelationship between affective, cognitive and perceptual processes. Moreover, aesthetic experiences that promote affective and often emotional responses associated with the dispositions like fascination, anticipation and engagement and awe, wonder and interest that spark curiosity, can lead to the use of scientific inquiry to develop explanations of natural phenomena (Milne, 2010).

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D4. Child–teacher interaction

Much literature in early years has criticised teacher-directed learning, highlighting how this can reduce engagement and children's creative thinking (Barrow, 2010). For example, Cremin (2009) highlights the central role of practice which fosters children's self direction and agency, which is achieved through an inclusive approach that expects and fosters independence from the very earliest years of schooling. However, considering interaction between children and the teacher simply in terms of child or teacher directed may obscure the more complex interaction, and the important role of the teacher in fostering learning through children's self expression.

D4.1 Play

Discourse around play is a useful example of considering the balance between children and teacher interaction. Whilst play is considered a paradigm of child-centred activity, the teacher plays a key role in organising the play environment, and for leveraging play to help children think about certain ideas. Indeed, undirected play may not be beneficial for learning (Goswami, 2004; Goswami and Bryant, 2007). However, rather than direct play, it is possible for teachers to guide children's attention to certain ideas through play; for example by acting as partners with children during play.

It is important therefore to consider the teacher's role in different activities such as play. Indeed, according to Cindy et al. (2007), criticisms of approaches such as inquiry or problem based learning often make the error of comparing them to discovery learning. The authors highlight the need to consider the role of the teacher in scaffolding the learning process through different activities.

D4.2 Scaffolding

More than 35 years ago, Wood, Bruner and Ross (1976) introduced the idea of 'scaffolding' to represent the way children's learning can be supported by gradual removal of teacher support. This approach has resonance with the widely accepted notion in teaching in the constructivist paradigm for learning (Anghileri, 2006). Scaffolding has been considered particularly beneficial for young children by fostering their independence in areas ranging from inquiry (Metz, 2004), conceptual knowledge (Coltman, Petyaeva and Anghileri, 2002), strategies (Secada, Fuson, and Hall, 1983), problem-solving (Rittle-Johnson and Koedinger, 2005) and even meta-cognitive strategies (Aleven and Koedinger, 2002).

The notion that children will need less teacher support over time seems quite clear. However, the broad remit of scaffolding does highlight the need to consider what skills or understandings should be focused upon. It is also important to consider how teacher support may be more dynamic than a simple reduction over time. Finally, scaffolding is often discussed in terms of helping children gain independence *in a specific task/skill*. This could be considered to contradict the notion of encouraging children's alternative

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thinking. It may therefore be more productive to consider exactly what skills or understandings we wish to encourage. One aspect may be children's verbal reasoning through dialogue as discussed subsequently.

D4.3 Dialogue

Language plays an important role in science learning (Carlsen, 2008). According to Roth (2007), talk is a means by which we navigate and know the world and a medium in which we 'do science'. Through talk children are able to externalise, share and develop their thinking, and participate in a science community within the class (Mercer and Littleton, 2007; Mercer et al., 1999). It is important to consider other modes of communication beyond speech however, particularly for young children – allowing children to express ideas through gesture, drawing or simply through their actions. All these modes of communication provide ways for the teacher to listen and foster dialogue that builds upon children's own ideas. Moreover, by considering more than one mode, it may be possible to identify inconsistencies in children's thinking; for example, mismatches between speech and gesture (Goldin-Meadow, 1997).

Listening to children's initial ideas in an area respects the child's view (Coltman et al., 2002), and can emphasise the validity of alternative points of view: they are not simply 'misconceptions' as often referred. Moreover, children may hold 'correct' answers for the wrong reasons; that may only be identified through explaining their ideas. Discussion has the potential to reveal the reasoning behind children's views that often makes sense within the children's own terms and experience. However, whilst the classroom provides opportunities to develop young people's ability to construct arguments, these opportunities may be impeded for reasons such as teachers' lack of skills and knowledge (Driver, Newton and Osborne, 2000).

D4.3.1 Questioning

Teachers who use a lot of questions achieve very good levels of pupil involvement and promote learning (Rojas-Drummond and Zapata, 2004). However, the form of questioning used by teachers has been considered significant in encouraging children to consider alternative ideas. Where closed questions expect specific responses, more open questioning is intended to promote greater speculation and the generation of possibilities (Craft, Jeffrey and Leibling, 2001; Robertson, 2002).

For younger children, who are less familiar with particular formal discourses, open-questioning may elicit a more personal response (Harris and Williams, 2007). Given the importance of building on personal meaning, this can be seen as positive; however, teachers (particularly those in training) may find such wide responses to questions difficult (Inoue and Buczynski, 2011). Indeed, it is arguably not clear how teachers are able to foster dialogue around personal responses of one child so as to engage other children. Another aspect to consider with open-questioning is that children may find this difficult if they have little experience of this form of questioning at home (Harris and Williams, 2007). However, Harris and

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Williams suggest that rather than the dimension open and closed questioning, it may be preferable to draw upon linguistic theory to consider the relationship between children's understanding of questions and the referential codes in the questions (e.g. whether they refer to objects that are present). In this regard, it is possible to consider how the teacher may use certain materials or gestures to help ground questions to support children's thinking.

In science, Harlen and Qualter (2004) also draw attention to the different kinds and purposes of questioning for example, whether they are person or subject centred, or designed to foster inquiry or to explore ideas. They indicate that questions can be framed for different purposes and emphasise the importance of giving time for thinking and response.

The approach in open questioning of encouraging alternative ideas can be likened to the strategy of brain-storming. Most brainstorming instructions are based on Osborn's original instructional components (Osborn, 1963, p.156). These are: (1) Criticism is ruled out. Adverse judgment of ideas must be withheld until later. (2) 'Free-wheeling' is welcomed. The wilder the idea, the better; it is easier to tame down than to think up. (3) Quantity is wanted, the greater the number of ideas, the more the likelihood of useful ideas. (4) Combination and improvement are sought. These components echo the notion of alternative thinking. Indeed Mirzaie, Hamidi and Anaraki (2009) showed that using the brainstorming technique with science activities improved children's creativity (as measured by the Torrence test (Torrance, Gowan, Wu and Aliotti, 1970).

D5. Forms of representation and expression

Materials used in the classroom offer different ways to represent ideas and allow children to express their thinking. Whilst the focus here is on the classroom environment, it is important to recognise children's experiences in other informal environments.

D5.1 Out of class experiences

Children's experiences in the home or contexts such as museums may provide them with a wide range of personal, embodied, experiences from which to draw upon in the classroom. Sometimes it will be possible to bring in certain materials into schools to foster children's curiosity. According to Milne (2010), 'A Sense of Wonder, Arising from Aesthetic Experiences, Should Be the Starting Point for Inquiry in Primary Science'. An interesting example is the 'Wonder Room' in a school in Nottingham, UK[2] – a room based on Museum's concept of 'cabinets of curiosity' (Figure 1).

[2] http://www.guardian.co.uk/education/2011/may/31/wonder-room-nottingham-university-academy

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Figure 1: Children's exploration of natural objects in the Wonder room, Nottingham, UK

Outdoor experiences at school may similarly tap into children's naturally curiosity about their environment. Indeed, outdoor activity is an integral part of various science programmes such as ScienceStart! (French, 2004). According to Waite, outdoor learning is valuable but limited by certain barriers that exist, such perceptions of how such experiences conflict with drives for improved educational standards (Waite, 2011). This can represent a missed opportunity (Maynard and Waters, 2007).

D5.2 Physical materials

With a history stretching back to pioneers such as Froebel and Montessori, physical materials such as blocks or tiles have been used to support young children's thinking. However, research on their effectiveness is limited (McNeil and Jarvin, 2007; Uttal, Scudder and DeLoache, 1997). This may be because effectiveness in this context is measured in terms of specific learning objectives, which makes it difficult to assess their value in helping children's more diverse thinking.

One way physical materials may help children is by allowing them to explore and test different ideas. For example, in Martin and Schwartz' study of physically distributed learning previously discussed, simple tiles allowed children to explore different spatial configurations to explore different numerical groupings. Furthermore, using video analysis, Manches, O'Malley and Benford (2010) highlight the wide range of actions children employ when using physical materials in numerical problems, and how many of these actions (e.g. swapping over groups, comparing stacks, identifying how amounts can or cannot be partitioned equally) reflect important mathematical concepts.

One enduring question in research is the relative benefits of concrete (real life) or more abstract (less extraneous features) materials. Various authors (Kaminski, Sloutsky and Heckler, 2009; Martin and Schwartz, 2005) argue for the benefits of more abstract materials that limit extraneous features that may distract children. There is a possible tension therefore of counter arguments that more concrete materials may be more apt for helping children relate to prior experiences. However, it is important to consider that the arguments for abstract materials tend to occur in mathematics, and more concrete materials in science.

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D5.3 Visual representations (diagrams / drawings)

Other forms of representation may be underused in helping children express their thinking. With paper, children are able to construct their own representations, which may proffer an advantage over 'presented' representations (Cox, 1999). Drawings and visualisations may help children in the transition from everyday thinking to more formal scientific concepts and support metacognitive processes, for example exploring increasingly complex ideas through being encouraged to revisit, revise and dialogue through and with their drawing (Brooks, 2009). Interestingly, when asked to use visual representations in problems solving Deliyianni, Monoyiou, Elia, Georgiou, and Zannettou (2009) found a significant difference between kindergarteners and first year children. Whilst younger children were more likely to draw descriptive pictures about the meaning of the problems, First graders, gave a routine solution, that is, a symbolic answer to problems, complying with the didactical contract rule that every problem given to them has an answer.

The use of children's visual representations has been the focus of work by Worthington and Carruthers (Carruthers and Worthington, 2005; Worthington, 2006; Worthington and Carruthers, 2003), building on Martin Hughes work previously discussed. Like Hughes, they believe that children's mark making provides a creative avenue to express their mathematical thinking. They also believe that such marks are widely neglected as a rich source for assessment of children's thinking.

D5.4 Digital materials

There are many advocates of new forms of digital materials in helping children explore ideas in areas such as mathematics and sciences (Clements, 1999; Moyer, Bolyard and Spikell, 2002). Benefits of digital materials range from the theoretical (ability to dynamically link forms of representation, provide a record of interactions) to the more pragmatics (easier to set up and share). The greater vision, expressed by the Papert (1980), a pioneer in the field (and student of Piaget), is that computers can provide new windows into thinking, allowing children to externalise, explore and evaluate 'powerful ideas'. Various authors have also claimed that technology is able to support inquiry (Capobianco and Lehman, 2006; Wang, Kinzie, McGuire and Pan, 2010).

A difficulty however is that interaction with computers is typically with a mouse, which may be challenging for children under around 5 or 6 years old (Donker and Reitsma, 2007). There are also arguments that the form of interaction with a computer limits many important physical learning mechanisms (see Manches and O'Malley, 2011). In this light, emerging technologies may offer exciting opportunities for young children. From tablets (e.g. iPad) to gesture recognition and tangibles (digitally augmented physical objects) there are exciting new ways that children can explore ideas with digital materials. Clearly, however, the benefits of these materials will be mediated by how they are presented in class, where the

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teacher's own confidence and beliefs will play a key role (Karemaker, Pitchford and O'Malley, 2010).

D5.5 Gesture

As well different materials, it is important to recognise the growing research on how gestures provide children with a way to externalise their thinking and may play an important role in the learning process (Goldin-Meadow, 2009). Children (and teachers) gesture naturally everyday settings (Flevares and Perry, 2001) and gesture research has recently gained much attention as a window into children's nascent understandings of different concepts. Children are often able to express thinking in gesture before they can do so through speech (Goldin-Meadow, 2009), indeed mismatches between their gestures and speech indicate children's preparedness to develop their thinking (Goldin-Meadow, 1997). Consequently, gestures provide a window through which to assess children (Kelly, Singer, Hicks and Goldin-Meadow, 2002).

D6. Assessment

As the aims of science and mathematics education change, the means by which we assess children need to adapt. This has prompted work offering new types of test, for example of children's scientific literacy (Carstensen, Lankes and Steffensky, 2011) and calls that the EU should invest significantly in research and development work on assessment in science education; with the aim of developing items and methods that assess the skills, knowledge and competencies expected of a scientifically literate citizen' (Osborne and Dillon, 2008).

Furthermore changing perspectives on learning and teaching and development in the field of assessment have led to a growing debate about the purposes of assessment and an increased emphasis on the importance of assessment for learning as well as of learning (Black, 2001; Gipps and Stobart, 1997). Two different purpose of assessment are highlighted.

D6.1 Formative assessment

Assessment is used formatively only when it informs the learning process directly (Black, 1998). In other words, teachers, children (and possibly parents) are able to use assessment information in order to identify how to improve. The central role of formative assessment in teaching and learning processes is to seek to build on the skills, attitudes, knowledge and understandings children bring to school, support and encourage children's active engagement in learning and foster awareness of their own thinking and progress. Harrison and Howard (2011) highlight the key roles of feedback, sharing criteria with learners, questioning and self-assessment in promoting effective learning. The role of children in assessment is particularly significant when considering how evaluating ideas is an important learning process. This may include peer assessment as well as self-assessment, thereby contributing to community aspects of the class.

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Many proponents consequently argue that a more holistic approach to assessment, taking into account the child's physical, social, emotional, linguistic, attitudinal, and cultural background, is most effective. However, assessing such attributes requires the development of tools and criteria to support teachers in assessment. It is also important to consider the demands placed on broadening assessment for multiple children in the classroom.

D6.2 Summative assessment

Summative use of assessment refers to the use of assessment information at a particular point in time to compare children over time and space; for example, how individuals or cohorts have improved or as a means to compare children. Such results may be reported to parents or used for monitoring or accountability purposes. In order for such comparisons to be made, the concept of 'replicability' is considered important – that measures are independent of time and place. Consequently, summative assessment by its nature attempts to remove the role of environmental and social factors: the factors highlighted as playing a key role in children's thinking. This is highly significant when considering how the summative use of assessment can drive teaching and learning,

The above attempts to provide a relatively simplistic account of the tensions surrounding summative assessment (particularly high-stakes (Taylor, Jones, Broadwell and Oppewal, 2008)), and the challenge of developing forms of assessment that capture the rich nature of children's learning in context. This difficulty is also significant in research attempting to identify relationships between variables. As an example, it was found by that there was no relationship between children's measures of mathematical ability and creativity (Baran, Erdogan and Váakmak, 2011). Mathematics ability was measured through the TEMA-3 (Ginsburg and Baroody, 2003) and creativity through the Torrance Test (Torrance et al., 1970). It is possible to question how much these tests reflect the concepts they attempt to measure. The TEMA-3 for example, focuses upon areas of mathematics such as less-more, counting, informal calculation, numbers, relations between numbers, calculation and decimal concepts. The Torrance tests measures creativity through children's alternative ideas in visualisation tasks (consisting of the three sub-tests of picture formation, picture completion and parallel figures). Rather than examine how creativity is expressed through mathematics, therefore, the study concludes no relationship by the lack of correlation between two de-contextualised measures.

D6.3 Multimodal assessment

One way in which assessments are standarised is through a focus on a limited ways for children to express their thinking. Glauert (2009a) highlights the need to adopt a multimodal approach to assessment – for example, attending to children's speech, gestures or visualisations as discussed in this paper. Capturing children's ideas through different media

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also presents ways for the teacher, and child, to explore variations in thinking. Clearly, there are additional pressures of trying to capture different modes of thinking. In this regard, technology may offer support. In the same way that tools such as video and storage can provide researchers with a richer picture of the learning process, these tools may support teachers in capturing, sharing and reflecting upon children's learning in science and mathematics. Indeed, this is one of the purported benefits of e-portfolios for assessment (Stefani, Mason and Pegler, 2007). However, whilst this range of information about children is not recognised as standard summative assessment, there may be less motivation for teachers.

D7. Teacher factors

Interactions between children and the teacher as well as the materials provided will be greatly affected by the teacher's personal characteristics; namely their own knowledge, confidence and beliefs. Teachers' subject knowledge will shape the approaches they adopt. For example, in science, lack of teacher knowledge can lead to reliance on activities that work from other disciplines e.g. literacy, social studies, hands-on activities (Appleton, 2003). Teachers' subject knowledge can also affect their confidence. Indeed, Ofsted (official UK body for inspecting schools) reported that lack of teacher confidence (owing in particular to weak subject knowledge and concerns over test results) were barriers to creativity (Ofsted, 2010). In Turkey, Bursal (2010) found that teachers' degree of self-efficacy in mathematics and science impacts on their use of inquiry, manipulatives and student-centred strategies.

According to Fleer (2009), teachers' philosophies are more important than their knowledge or confidence. In a study of successful mathematics teachers, Askew, Brown, Rhodes, Johnson, and Wiliam (1997) found that what distinguished highly effective teachers from other teachers was a particular set of coherent beliefs and understandings, which underpinned their teaching of numeracy. The beliefs included what it means to numerate and determined, for example, what type of questions teachers asked and how they followed them up, irrespective of whether they were talking to pupils individually, in a group or in the whole class. This reflects work by Iannone and Cockburn (2008), who investigated how teachers can foster conceptual mathematical thinking in five- and six-year-old pupils in a classroom situation. From their work, they concluded that pupils are more consistently engaged in conceptual mathematical thinking in the classrooms with teachers who view mathematics as a web of interconnected ideas, and perceive it as being about general structure and patterns.

D8. Creativity in science and mathematics learning

In section 2, it was discussed how the changing perspectives on science and mathematics education and young children helped explain increasing rhetoric surrounding the role of creativity in learning. This section has

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focused on how research into teaching and learning might help deconstruct this rhetoric.

Creativity is commonly taken to mean successful activity intent on producing something novel (Newton, 2010). Moreover, the results of this activity must also be validated by society which rules on what is appropriate, suitable, effective or valuable (Csikszentmihalyi, 1997). In this light, creativity in the classroom might suggest activity regarded most valuable by the teacher and peers. This may help explain the link that continues to be discussed between creativity and giftedness (Sriraman and Lee, 2011). In fact, this interpretation of creativity echoes Bloom's (Bloom and Eisner, 1971) notion of creativity as higher order thinking, with knowledge-acquisition more lower order.

However, linking creativity with giftedness emphasises relative achievement, not learning. In terms of learning, creativity emphasises how children produce ideas that are novel to them, and how they learn to evaluate these ideas. In this regard, it is possible to relate creativity to the frequent references to alternative thinking discussed in this review. We can reflect on the role of creativity by considering two phases: generative and evaluative (Robinson, 2001).

D8.1 Generative

This section has discussed the cognitive benefits of alternative thinking in learning: how children are able to reason between different strategies or explanations. Providing children with different modes of communication can help them express different ideas, or communicate ideas with peers collaboratively in the class community. Importantly, recognising the importance of attitudes and motivation in thinking can provide children with the confidence and willing to put forward their own ideas, drawing upon personal experiences from within or outside the class.

D8.2 Evaluative

As well as generating different possibilities, children need to evaluate which of these present more valuable, effective explanations, or strategies for different problems. This often requires reasoning about multiple variables, placing demands on cognitive processes. Different activities, such as those building children verbal skills, can develop children's metacognitive abilities; however, it is important to recognise the role of children's environment in helping children offload processing. Different materials not only help children externalise different ideas but provides an opportunity to inspect and reflect upon these ideas.

D8.3 Simplistic dichotomies

In their paper on creativity in science education, Kind and Kind (2007) highlight a tendency to identify creativity with 'good' teaching and lack of creativity as 'bad'. Moreover, they identify a range of dichotomies that structure this good creative teaching versus bad traditional teaching as illustrated in Figure 2.

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'Good' creative teaching		'Bad' traditional teaching
Student-oriented	v.	Teacher-oriented
Group/team work	v.	Individual work
Cooperative learning	v.	Individual learning
Explorative tasks	v.	Close-end tasks
Open-ended problems	v.	Closed problems
Open investigations	v.	'Recipe' work
Hands-on teaching	v.	Lectures
Outdoor activities	v.	Classroom activities
Project work	v.	Lectures
Issue-oriented	v.	Concept oriented
Teachers taking risks	v.	Teachers playing safe

Figure 2: Common contrasts in discourse relating to creativity (Kind and Kind, 2007, p.4)

Whilst referring to older students, it is possible to see how many of these dimensions identified above could map to themes discussed in this paper. Therefore, as argued in Kind and Kind's paper, it is important to be critical toward certain simplistic dichotomies when trying to understand the complex nature of teaching and learning, and consider how the dynamic context requires a range of approaches over time.

D8.4 Summary

The aim of this section has been to identify significant themes in research about learning and teaching in young children's science and mathematics education. These included, for example, the role of physical materials in grounding conversations and helping children offload the demands of considering alternative ideas, or the possible benefits of realising young children's potential for collaborative scientific reasoning. Other themes to emerge include the value of providing children with different ways to express their thinking, and how this might be integrated into new forms of assessment. And how emerging digital technologies may offer engaging ways for children to explore ideas and possibly play a role in capturing and recording thinking, allowing children to evaluate their own and others ideas.

This section also highlighted some gaps in our understanding, for example, in the benefits of children learning about the nature of mathematics through re-creating their own symbolisms, children's own use of questioning, or the relative benefits of concrete or abstract materials. There also appeared to be limited research on strategies to improve children's attitudes to science given the fundamental importance of affective factors.

The themes in this section therefore demonstrate that creativity does seem to provide a valuable window in which to examine children's science and mathematics learning. However, if the concept of creativity is to inform pedagogy, it is important to move beyond simple associations of creativity with positive dimensions of teaching, and understand how specific approaches can help children generate and evaluate ideas in ways that

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supports their learning. In this respect, it is worth focusing on how creativity differs from approaches in inquiry based learning that advocate many of the themes discussed and has significant currency in educational policy and research.

E. Inquiry-based education

Inquiry can be defined as 'the intentional process of diagnosing problems, critiquing experiments, and distinguishing alternatives, planning investigations, researching conjectures, searching for information, constructing models, debating with peers, and forming coherent arguments' (Linn, Davis and Bell, 2004, p.4). Inquiry Based Education reflects the recommendations of Dewey over 100 years ago who considered that there was too much emphasis on facts without enough emphasis on science for thinking and an attitude of the mind. In Dewey's model, the student is actively involved, and the teacher has a role as facilitator and guide. According to Drayton and Falk (2001, p.25), 'The inquiry-based approach to science education [...] introduces students to the content of science, including the process of investigation, in the context of the reasoning that gives science its dynamic character and provides the logical framework that enables one to understand scientific innovation and evaluate scientific claims. Inquiry is not process versus content; rather it is a way of learning content'. Whilst the term of inquiry has been predominately science education, Rocard et al. (2007) suggest that it also encompasses problem based learning in mathematics.

The National Research Council (2000) identifies five attributes of learners in Inquiry Based Education 1) Engages in scientifically oriented questions, 2) Gives priority to evidence in responding to questions 3) Formulates explanation from evidence, 4) Connects explanations to scientific knowledge, and 5) Communicates and justifies explanations. Barrow (2010) illustrates how placing these five dimensions on a scale indicates the level of student or teacher direction in a tool for assessing inquiry (and teaching approaches) (Figure 3). The implication of this scale is that inquiry reflects greater student self-direction.

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Essential Feature	Variations			
Learner engages in scientifically oriented questions	Learner poses a question	Learner selects among questions, poses new questions	Learner sharpens or clarifies question provided by teacher, materials, or other source	Learner engages in question provided by teacher, materials, or other source
Learner gives priority to **evidence** in responding to questions	Learner determines what constitutes evidence and collects it	Learner directed to collect certain data	Learner given data and asked to analyze	Learner given data and told how to analyze
Learner formulates **explanations** from evidence	Learner formulates explanations after summarizing evidence	Learner guided in process of formulating explanations from evidence	Learner given possible ways to use evidence to formulate explanation	Learner provided with evidence
Learner connects explanations to scientific knowledge	Learner independently examines other resources and forms links to explanations	Learner directed toward areas and sources of scientific knowledge	Learner given possible connections	
Learner communicates and justifies explanations	Learner forms reasonable and logical argument to communicate explanations	Learner coached in development of communication	Learner provided broad guidelines to sharpen communication	Learner given steps and procedures for communication

More---------------------------Amount of Learner Self-Direction------------------------------Less

Less-------------------Amount of Direction from Teacher or Material--------------------More

Figure 3: Essential features of classroom inquiry and their variations (Barrow, 2010)

E1. Criticisms

Whilst Inquiry Based Education seems to capture many of the positive aspects of learning discussed in the paper, there have been criticisms, or identified limitations. With a focus on student self-direction, one argument proposed by Kirschner, Sweller, and Clark (2006) has been to group inquiry based and problem solving approaches with discovery learning – minimising the role of the teacher. However, this criticism is contested by Cindy, Duncan, and Clark (2007) who emphasise how approaches advocated by inquiry based learning actually employ quite a high level of scaffolding thereby reducing the cognitive load and allowing students to learn in complex domains.

Considering the important role for the teacher, one possible limiting factor of inquiry approaches may be the skills and approaches adopted by teachers. Indeed, Kind and Kind (2007, p.10) suggests that teachers may 'inevitably frame students' investigations ('inquiries'), either by providing a fool-proof 'recipe', restricting apparatus or providing heavy guidance towards a specific route for achieving a solution'. Indeed, in an analysis of essential features of inquiry found in articles published in the science Teacher between 1998 and 2007, Asay and Orgill (2010) found a dominant focus on 'gathering' and 'analysing' which they argue may reflect teachers' views of inquiry. Moreover, the majority of inquiries were teacher not student led. There is, it seems therefore, potential to support teachers in developing inquiry teaching methods, however, this difficulty may simply reflect how teachers resort to less demanding teaching (for them and

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students) due to assessment demands and a crowded schedule (Minner, Levy, and Century, 2010).

Kind and Kind (2007) suggest that teaching factors may help explain why there has been limited empirical work demonstrating the benefits of Inquiry Based Education. However, as previously discussed, the validity of this empirical work will depend upon the measures used to assess learning. It is possible that inquiry based approaches develop aspects such as attitudes and understanding of science that tend to be underrepresented in standard assessments. Indeed, in a study of Turkish elementary students, it was shown that use of inquiry based teaching methods significantly enhances students' science process skills and attitudes (Simsek and Kabapinar, 2010).

E2. Inquiry-based education in the early years

According to Metz (1998), scientific inquiry is within reach of young children. Metz identifies a number of limitations in children's investigations, but over time, children improve strategies, and shift in emphasis from making things happen to development of understanding. This need for time is emphasises also by Glauert (2009b, p.46), who proposes that "over time [children] may begin to raise questions for investigation, look for patterns and relationships and begin to offer explanations'. Lind (1998) also argues for role of scientific enquiry in young children's education but emphasises the need to consider the child's cognitive capacity when developing science instruction and maintains that when there is a mismatch, children are unable to extend, apply, or interpret deeper meanings of the content, and their interest and positive attitudes are likely to diminish. Akerson and Donnelly (2010) carried out a 6-week intervention programme on K-2 students' views of nature of science (NOS) with explicit reflective instruction through contextualised and decontextualised, guided and authentic, inquiry. Their results indicated that K-2 students improved their NOS views over the course of the programme, suggesting that they are developmentally ready for these concepts. Students developed adequate views of the distinction between observation and inference, the creative NOS, the tentative NOS, the empirical NOS, and to a lesser degree, the subjective NOS. Subjective NOS refers to an understanding that science is fundamentally a subjective processes – perhaps explaining children's belief that they are learning objective facts in science and mathematics.

E3. Inquiry-based education and creativity

Inquiry Based Education seems to adopt many of the approaches that might be considered to offer a creative perspective on science and mathematics education. Emphasis is on children generating personal meaning and the skills to reason through their thinking. Indeed, many of the terms and themes used to discuss inquiry overlap with creativity – such as the role of critical evaluation, personal meaning, collaboration, scaffolding, or positive attitudes. A key question therefore is what does creativity add to our understanding of pedagogy above and beyond inquiry.

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The first point to consider is that creativity and inquiry should not be seen in juxtaposition, but rather creativity may help emphasise particular aspects within an inquiry approach. Whilst inquiry emphasises the student pursing a personal line of thinking, creativity, as discussed in this paper, places emphasis on the generation of alternative lines of thinking. These alternative lines of thinking may be generated by the individual or as part of a community. Accordingly, creativity also places emphasis on processes of evaluation between alternatives.

DeHaan provides a much more complex and reasoned examination of the link between creativity and inventive problem solving, drawing upon higher order cognitive processes (DeHaan, 2009, p. 172): 'Evidence suggests that instruction to support the development of creativity requires inquiry-based teaching that includes explicit strategies to promote cognitive flexibility. Students need to be repeatedly reminded and shown how to be creative, to integrate material across subject areas, to question their own assumptions, and to imagine other viewpoints and possibilities. Further research is required to determine whether college students' learning will be enhanced by these measures'.

It is possible, that creativity does not contradict any of the approaches offered by Inquiry Based Education. Yet, the slight difference in emphasis may have significant implications. For example, the implications for children's motivation and confidence in order to identify a different idea to one offered. There may also be benefits for children in considering the relative merits of different ideas – how ideas cannot simply be categorised in terms of right or wrong. Critically evaluating alternatives may also develop children's ability for self-assessment. And being more attentive to other's ideas may support collaboration. Clearly, such possibilities are speculative, however, they do warrant further investigation to evaluate such possibilities in supporting children's science and mathematics education.

F. Policy in science and mathematics education in the early years

F1. Introduction

Educational policy can shape practice by emphasising values, and by indicating what should be taught and how through frameworks and expected outcomes. In this project, we have the potential to add to current EU reviews of policy in mathematics and science education a) in our focus on pre-primary education (addressed to a limited current reviews of mathematics and science education) – and on the early years of primary education (commentary is often made on the primary phase as a whole - without reference to any differences in approach, issues and progression across the primary years); and b) in our specific emphasis on links between science and mathematics and the potential for creativity.

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In order to contribute to policy, we first need to develop a picture of how creativity plays out in current Consortium policy documents, thereby identifying possible tensions and gaps and possibilities to inform policy. This is the main objective of Work Package 3. This section presents and reflects upon an initial review of (government) policy contexts for science and mathematics in the early years of education to identify dimensions that might be explored in WP3.

F2. Creativity in European early years science and mathematics education policy

The purpose of the initial review was not to undertake a detailed analysis of policy in each country but to draw out themes and issues that might be explored more systematically and in depth in WP3. In this aim, this review took account of key themes in the project proposal: identifying the potential for creativity: supporting emergence of appropriate learning outcomes, avoidance of misconceptions and stereotypical images, attracting interest, improving basic skills and promoting creativity. The review focused on identifying the potential for creativity in policy by making connections with dimensions and issues from the examination of research carried out in the previous sections of this document. These might help characterise creativity in science and mathematics learning and teaching, such as an emphasis on particular attitudes and processes of mathematics and science learning associated with creativity or particular teaching approaches, for example, promotion of active, inquiry-based learning and critical thinking.

As such, this initial review may be able to suggest starting points for the identification of factors associated with WP3. In turn this may set the context for an examination of opportunities and challenges in promoting IBE/PBL and creativity in different policy contexts and of ways in which teachers negotiate and interpret policy guidelines and requirements in WP4. Levin (2001) highlights the dynamic interactions between policy and practice in a climate of continued policy change. There is evidence of this in the ways in which policy rhetoric related to IBE and creativity has become the focus of attention in early years and primary practice – but the challenges of implementation in a climate of increased accountability.

F3. Initial review

F3.1 Introduction

F3.1.1 Early years: Pre-school and Primary

This project focuses on the early years, which includes two discernable phases of education: pre-school and the initial years of primary schooling. The ages in which children start these phases differ between European countries. Table 1 illustrates ages of phases across Consortium countries.

Pre-school education is provided across the consortium from the ages of 2 or 3. In some instances pre-school provision is not the responsibility of the Ministry of education e.g. Germany. The starting age for compulsory schooling and the start of primary schooling varies across the consortium.

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In the majority of countries primary schooling starts at 6 –with Malta and the UK starting earlier at 5 and Finland later at 7.

Partner country	Pre school	Primary
Belgium (French)	2.5-6 years	6-12 years
Belgium (Flemish)	2.5- 6 years	6-12 years
Germany	2/3-6 years (Ministry of education not responsible) 5-7 years optional pre-school classes and kindergarten (Ministry of education is responsible)	6-10 years in some Federal states 6-12 years
Greece	4-6 years - compulsory for 5 year olds. No National Curriculum for children attending child and infant centres (1.5-4 year olds) and Ministry of education not responsible)	6-12 years
France	2-6 years - education compulsory from 6 years	6-11 years
Malta	3-5 years	5-11
Portugal	3-6 years	6-10
Romania	3-6 years	6-10
Finland	3-5 Early Childhood education Preschool 5-6 years	7 – integrated primary and lower secondary
UK (England)	3-5 years	5-11
UK (Wales)	3-5 years	5-11
UK (Northern Ireland)	3-4 years (preschool) 4-6 years(foundation stage)	6-11
UK (Scotland)	3-5	5-12

Table 1: Pre School and School ages across Consortium nations

F3.1.2 Curricula Policy

Curricula in the early years of education are the focus of directives from education authorities in all countries. These may set out:

- *aims* - in terms of broad areas of knowledge, or skills, attitudes to be promoted – indicated through explicit statements of aims and/or reflected for example in learning objectives and curricula
- *curriculum* content
- *specific learning outcomes* to be achieved

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- *assessment* requirements and guidance
- *procedures for monitoring and evaluation*
- *approaches to learning and teaching*

The degree of regulation and the official status of documents vary (whether compulsory/statutory or guidance) across partner countries and phases of education. For example in some Consortium countries learning outcomes only are defined in statute. While guidance in relation to the curriculum may be provided, responsibility for determining the curricula may reside at a local level (by municipalities, schools or teachers) – for example Belgium, Portugal or Germany in relation to pre-school provision.

Requirements in relation to assessment also vary. In most partner countries the emphasis in pre-school is on ongoing formative teacher assessment with methods to be adopted determined by teachers, whereas in the England and Wales there are statutory requirements for summative assessment. In the primary years there is a greater emphasis on summative assessment against nationally/regionally set criteria. In some countries standardised tests have been introduced for accountability and evaluation purposes (at child/school/system levels).

It will be important to recognise the complexity of relationships between these elements and their influence on practice. As illustrated by Le Metais (1999) in a study of values and aims in curriculum frameworks across 16 nations there may be a mismatch between aims, curriculum requirements and assessment regulations. Or as highlighted by Laevers (2005) and Alexander and Amstrong (2010) statutory learning outcomes or testing arrangements may have a distorting impact on the nature and breadth of the curriculum. See also comment in EACEAP9 Eurydice (2011) 'the focus tends to be on the test content rather than curriculum standards or objectives' (p90).

In many of the Consortium countries policy is in transition with new policies in development or in the early stages of implementation. It would be useful to explore what seems to be the nature and direction of change and factors that have influenced the changes proposed. It is also important (although beyond the scope of this initial review) to consider the historical context surrounding national policies as this can highlight the significance of what is emphasised as well as what is not said or assumed.

F3.2 Method

F3.2.1 Template

In order to tease out any emerging themes, partners were asked to summarise policy documents of their respective countries using a template based on the major policy elements listed above. However, it was decided to group aspects relating to assessment, outcomes and monitoring to one heading and also to include Inquiry Based Education considering its role in this project. This resulted in the following headings:

- Aims for science and mathematics education

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- Curriculum content – key topics, areas of study
- Approaches to learning and teaching
- Ways in which IBSE is promoted
- Assessment approaches and formal assessment requirements

The aim was to use these broad headings to tease out possible issues and dimensions given the time limitations for partners at this stage of the project. However, this process highlights the challenge, and importance, of identifying the right dimensions and categories with which to analyse documentation in WP3. Suggestions are presented toward the end of this section.

F3.3 Findings

As expected, differences in detail between individual templates highlighted a significant challenge. Whilst not a major issue for this initial review, differences in approach highlight the limitations of conclusions that can be drawn through comparisons of templates, for example whether levels of detail relating to the role of creativity reflect the policy or level of interpretation. Whilst this may seem obvious, it does suggest that level of detail needs to be clarified, or possibly categorised – ranging from simple high level (e.g. presence of certain terminologies) to fine detail (e.g. account of integrating processes). The aim here therefore is simply to extract significant themes to emerge between policy templates rather than make explicit comparisons between countries.

F3.3.1 Aims and emphases in science and mathematics education

Common themes in policy for science and mathematics education in the early years include the need to foster positive attitudes to science and mathematics, to enhance knowledge about the world, to develop skills and understandings associated with inquiry and to promote a questioning and investigative approach to learning (European Commission 2011). Similar themes highlighted in the templates are summarised below.

Attitudes

There is a widespread reference to the need to develop positive attitudes across both phases and subjects. This is often in general terms, referring simply to attitudes, however, more specific terms include curiosity, interest, motivation, and self esteem. It is also interesting to reflect on language of fostering or 'stimulating' positive attitudes – a possible indication that these need to be generated rather than existing previously. There is also mention of developing critical attitude, highlighting the cognitive as well as affective dimension of attitude. Critical attitude may be important with respect to evaluation aspects of creativity.

Skills and processes associated with inquiry and learning

Skills and processes are a key focus in all templates across phases and subjects; however, their interwoven nature makes it difficult to discern patterns. There is widespread reference to exploration, investigation and problem solving, and a common emphasis on observing and communicating

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(in some instances reference to varied approaches to representation e.g. Finland). In some instances there is specific reference to reasoning (e.g. Portugal), explaining (e.g. France), evaluating (e.g. Wales, Malta) but this is less common. There is less mention of integrated processes such as questioning or predicting.

Creativity is sometimes referred to (notably in Scotland), however, more as an independent (reified) entity to be fostered alongside other aspects, e.g.' promote greater flexibility and creativity' (Scotland), 'develops curiosity, creativity, critical thinking and interest in the scientific and technical progress' (France) or 'mathematical thinking i) creative thinking ii) reflective thinking iii) critical thinking' (Greece). In Wales, the phrase, 'Activities should foster curiosity and creativity and be interesting, enjoyable, relevant and challenging for the learner' suggests that creativity is something distinct from these other aspects. In the England, the national curriculum document previously listed thinking skills (including enquiry skills, creative thinking skills, reasoning skills and evaluation skills); key skills such as problem solving; and creativity that were to be applied across the curriculum.

Knowledge and understanding

Science knowledge and understanding is represented in very general terms only in aims – such as reference to the natural environment, the world around children, or technology. More details are provided in curriculum requirements or guidance. In mathematics, there is a greater indication of some learning expectations in relation to key strands such as number, shape and space, measuring, data handling.

Links to society and applications

Considerable reference is made to connections with everyday life – society and culture. This is widespread across phases and issues in society – more common in primary phase but also environment (e.g. Finland), sustainability (e.g. Greece), links with technology (e.g. England, Malta). In Flanders environment, technology and health are combined with science in the area of learning 'World Orientation'.

Approaches to learning

Although a heading itself, approaches to learning were also identified often in the aims sections of templates. Approaches highlighted were rather diverse, tending to reinforce emphases on attitudes, active learning and inquiry. Again this highlights the need to look across documents as features may appear in different places.

Summary comments

The process of trying to draw themes highlighted the tendency often toward the use of certain terms. In this regard, an interesting exercise was to create a simple visualisation of word frequency (using www.wordle.com) – Figure 4. By removing the main generic terms (education, Learning, science, mathematics, Children) it is possible to see certain terms emerge: environment, world, objectives, skills, concepts, materials, different,

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processes, technology, objects. Curiosity appears but creativity does not. Clearly, the use of terms out of context is a very crude form of analysis, but it does suggest patterns, and importantly indicates aspects of creativity – the use of materials to support thinking, making meaningful connections to society and the world – whilst not the term itself. However, it is also important to remember that often terms used are translations into English made by partners in the Consortium.

Figure 4: Word frequency visualisation of aims in templates (using Wordle)

It is possible also to use such forms of analysis to reflect upon missing terms – which can then be examined in greater detail. For example, the role of talk, discourse, or verbal, does not appear in the templates, although references to the role of talk in learning are often widespread in the more general sections of policy (e.g. Flanders, Finland). Technology does appear, but assessment does not. Whilst assessment is arguably a pedagogical process rather than an aim for children, this may indicate a gap for self-assessment, as well as peer-assessment. However no specific criteria were given to support the completion of the templates and their focus was primarily on mathematics and science. This may have contributed to the gaps identified. This process underlines both the importance of clear guidelines for policy analysis and the need to examine the full range of policy documentation. It raises also a more general issue about how generic and subject specific requirements and guidance are combined in teaching.

F.3.3.2 Curriculum

There are differing emphases on subject specific and generic skills across systems and phases – with greater focus, for example, on subject-specific requirements in the British education systems in contrast to the emphasis in Belgium on a broad core curriculum in which the child's personal development takes centre stage. In some countries, despite specification of a broad curriculum literacy and numeracy hold a dominant position.

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Areas of learning are defined in different ways – in many systems mathematics appears as a separate area of knowledge and skill, however science (in pre-school in particular) is often included within a broader grouping such as environmental or world studies or making links with technology; for example, in the early years in Belgium (Flemish community, 2.5 – 6yrs) 'World Orientation'; UK (England, 0-5 years) 'Knowledge and Understanding of the World' or in Greece (4-5 and 6-10 years) 'Environmental Studies', Portugal (3-6 years) 'Knowledge of the World and (6-12 Years) 'Environmental Studies'. However in the primary phase in UK (England and Wales) science is presented as a separate subject.

In preschool, science knowledge and understanding to be developed is often suggested in rather general terms through indication of broad topics to be addressed, although in many instances specific areas of study are not identified or required in the early years – an emphasis on processes and attitudes predominates. More precise detail is provided in relation to mathematics. In contrast, in Primary, there is a tendency for greater detail in relation to curriculum content across key areas of knowledge and understanding in science and mathematics, varied emphases on skills, processes and attitudes in specifications listed in templates.

Summary comments

It is interesting to match the curriculum sections to the aims. The curriculum sections focus more on particular content and more limited reference to processes and attitudes. A key issue is how aims and curriculum are reflected in the learning outcomes or assessment criteria. It will be important therefore in WP3 to include analysis of learning outcomes and assessment criteria.

F3.3.3 Approaches to learning and teaching

Contexts for learning in science and mathematics

In some countries, links between science and other subjects are not only indicated in the way that the curriculum is presented but encouraged in approaches to science teaching advocated - for example in preschool in Greece, Belgium, Germany where guidance encourages programmes built around cross-curricular topics and children's interests. References are made to linking everyday life and practical applications of science are common (e.g. Belgium Flemish, France, Malta).

Classroom environment

There is a great focus on the physical environment: the use of materials, and resources both in the indoor and outdoor environment (England), organisation of different areas of activity (Belgium), the social environment, collaboration, group work widely referenced across both preschool and primary phases – (e.g. Germany).

Types of learning activity – variety emphasised

There is widespread emphasis on active learning and building on children's existing knowledge and experience and interests (e.g. Portugal, Finland). In Flanders there is a particular emphasis on the individual talents and

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competences of children (linked to Gardner's multiple intelligences). The importance of play is highlighted in preschool guidance (Greece, England, Wales, Belgium). The most common references are to observation, practical hands on experience, investigative, problem solving experiences, discussion and communication of ideas and to promotion of positive attitudes, reflecting aims. There is also encouragement of autonomy and children's decision-making, reference to children's own project work (Germany). However, there is more limited detailed reference to ICT (although its significance across the curriculum is often mentioned, e.g. Greece) – either as a tool to support specific aspects of learning (e.g. self assessment) or the need to consider possible limitations of technology (e.g. constraining children's actions).

Teacher – child interactions – role of the teacher

There are varying degrees of reference to the balance between child-initiated and teacher led activities for example in UK (Wales), reference to co-construction in Germany.

F3.3.4 Ways in which IBSE is promoted (both implicit and explicit)

While links to IBE/PBL and opportunities for creativity might be identified in reviewing characteristics of the curriculum and learning and teaching approaches advocated – explicit references are limited in the documentation of many countries; although there appear to be more references in recent policy developments. In France, for example, there is an explicit reference to the IBSE for the primary school with the development of the project 'hands on' (la main à la pâte) and online resource for teachers from this project (there is also support for engaging scientists in primary classes). However, as IBE encompasses a wide range of processes, it is possible to see how implicit reference is also made across policy documentation. This again highlights the difficulty in focusing on terminology rather than the more implicit reference through approach.

F3.3.5 Assessment

The importance of formative assessment and ongoing evaluation is emphasised in most countries with teacher summative assessment of progress. In many countries there are no statutory assessment requirements. Monitoring and evaluation processes are in the hands of teachers and schools. We will need to examine the focus of these in WP3. There is evidence of increased use of national testing – either to sample standards or for reporting at school/child levels. There is variation in what is assessed. In some instances there are national/regionally defined learning outcomes or criteria, in others no formal requirements but guidance on the focus for assessment.

There is also variation in the modes of assessment – the range of approaches, such as observation in the pre-school emphasis, or the use of portfolio and self-assessment (Greece). Summative assessment in a number of cases is made in relation to assessment scales (England, Wales, Portugal). As might be expected, the use of tests is more evident in the Primary phase.

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F3.4 Summary in relation to creativity

Whilst it is difficult, even problematic, to draw any firm conclusions about policy from templates given methodological issues discussed, this initial review does elucidate possible issues to pursue or address in WP3.

The templates from the initial review included the use of terms that indicate potential for creativity as discussed in this paper. These include: positive attitudes, play, exploration and making links to the environment. Other aspects are not clearly represented such as building on children's home experiences, developing talk or using digital technologies creatively. Therefore, on one level, it would be possible to review policy documents simply for the presence or absence of terms indicating potential for creativity, although it is important to consider the effect of translation from different languages.

Whilst limited, the term creativity itself is also used in policy documents. However, creativity is often presented as goal in itself alongside other worthy pursuits such as curiosity or engagement. Consequently, the presence or absence of the use of term creativity itself seems a poor indicator of how creative approaches are integrated into the curriculum. What seems to be lacking is sufficient detail in policy documents to discuss the role of creativity within different learning themes. Figure 5 attempts to illustrate this.

It seems that the policy documents are written at a quite high level such that key learning terms (indicating potential for creativity) are identifiable, as so are terms more explicitly referring to creativity (or similar terms). However, there is insufficient detail to describe the integration of these concepts. Without such detail, it is difficult to evaluate the extent to which policy documents realise the potential of creativity in science and mathematics education for young children. It is very possible that other materials such as teacher websites or pedagogical texts do provide this detail.

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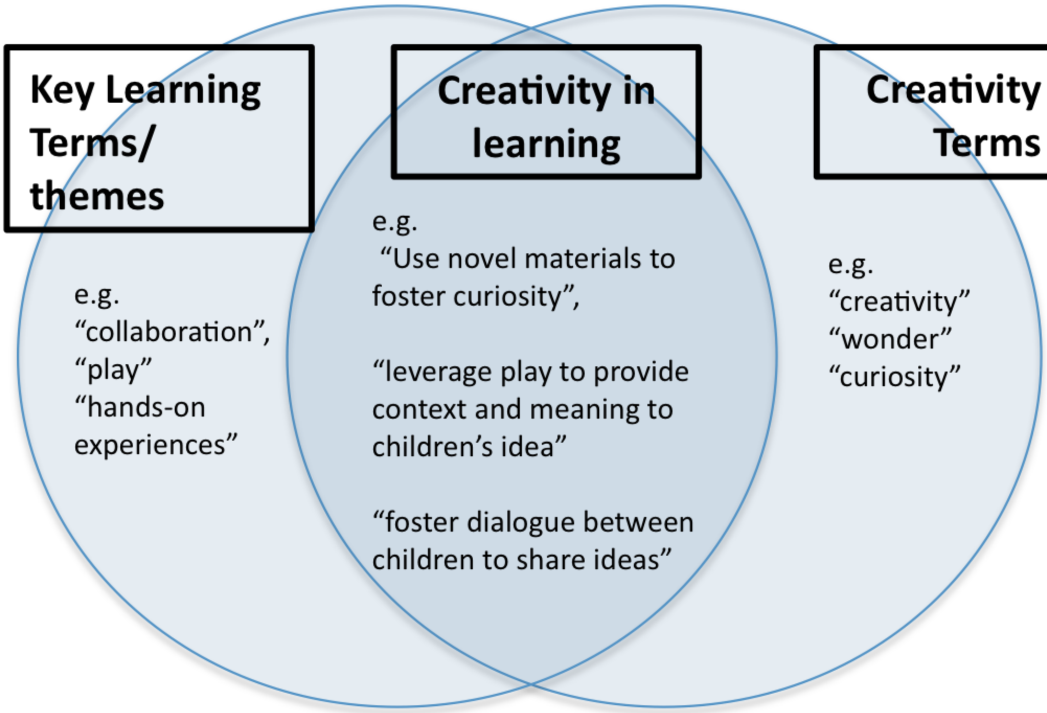

Figure 5: Intersection between creativity and learning themes

F3.4.1 Relation to themes from Research

Many of the themes from research are pervasive in the policy documents; most particularly are the themes of attitudes and links with society. The notion of processes as well as concepts does seem prominent in the aims of policies but it less clear whether the importance of scientific processes is emphasised in other sections such as curriculum. Whilst there is little explicit reference to providing children with a range of tools to express their thinking, there is reference to the role of teacher observation – highlighting how children's actions can illustrate their thinking.

As argued above, there is reference in policy to many key themes that research indicates as offering potential for creativity, yet insufficient detail is provided to clarify how these might be realised in teaching and learning contexts. There are also several themes discussed in the previous research section that seem to have much less prominence in policy documentation. These include the role of discourse, shared thinking, the use of digital technology (both benefits and limitations), different forms of expressing thinking (e.g. gesture, visualisations), and building upon children's personal experiences. Play is mentioned, but perhaps not as might be expected given the age group, and there is a notable decline in reference to play for Primary children.

F3.4.2 Potential for fostering creativity through policy

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This initial review highlights some of the limitations of policy – namely the trade-off between breadth and depth means that it is difficult to provide detail on how creativity can play a role within different learning themes. It is therefore important to consider how the potential of creativity might be fostered through materials linked to policy, as these materials may provide more detail – illustrating the integration of creativity in different learning themes. In this regard, it is interesting to consider the extent to which teachers use policy and related materials to guide their practice; and whether this changes over time (e.g. are teachers in training more likely to read policy?).

It is also clear that simply raising the profile of creativity may be ineffective if the meaning of creativity is not clear. Creativity is often expressed as a goal in itself rather than an approach, a lens to which view teaching and learning. If using the term creativity, it may be important to address preconceptions.

It is also important to consider the extent to which different aspects of policy impact on practice. It is possible that aspects such as explicit learning outcomes have more impact given their more tangible nature and may be used as criteria in accountability. Making creativity more tangible – possibly providing examples – may increase the potential to foster creativity through policy. This point highlights the importance of considering assessment when trying to foster particular learning approaches.

F3.4.3 Implications for WP3

This initial review has highlighted the significant methodological challenge of summarising policy documentation in order to make comparisons and evaluate in relation to creativity. The initial review was not that structured in order to adopt a more grounded approach for identifying themes. However, with multiple researchers, it was not clear where differences could be accounted for by actual policy differences. Multiple researchers may challenge the iterative process required in a more grounded approach, therefore it may be preferable to adopt a more structured approach – providing a clearer indication of what aspects to focus upon in policy analysis.

One possibility would be to use themes arising from the research section of this paper to guide the type of themes to explore in policy documentation, themes such as emotional (e.g. attitudes), physical (e.g. type of materials), or social factors (collaboration). However, as argued, in order to understand the role of creativity more fully, it would be necessary to consider the extent to which these are presented in relation to creativity. In this regard, one might consider a scale ranging from the mere presence of certain themes to a more in-depth integration of creativity in these themes as illustrated in figure 5.

There is also the methodological challenge of considering the policy as a whole. By doing so it may be possible to identify inconsistencies with individual policies, for example, one criticism of the Scottish new Curriculum for Excellence (CfE) is the tension between purported aims and learning

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outcomes (Priestley and Humes, 2010). When considering creativity, it will be particularly important to identify the integration of different themes within policies.

Another implication is to consider documents beyond policy. For example in Scotland, the emphasis on creativity is illustrated through resources such as a dedicated creativity portal3 documents such as 'Emerging good practice in creativity'4 as well as webpage discussing the importance of creativity and how it might be integrated into teaching and learning. In these resources it is possible to identify certain commonalities as well as differences in the themes discussed in this paper. For example, Figure 6 taken from the Scotland Learning and Teaching page suggests that creativity is a particular skill to be taught and is dependent on 'our imagination rather than our knowledge'. There are therefore different perspectives of the nature of creativity – and it is important to recognise these or risk not addressing existing criticisms.

Figure 6: creativity page from Learning and Teaching Scotland Portal

[3] (http://www.creativityportal.org.uk/),

[4] http://www.hmie.gov.uk/documents/publication/Emerging%20Good%20practice%20in%20Promoting%20creativitycreativity.pdf

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In order to evaluate the potential impact of policy on practice it is also important to consider the different effects of different aspects of policy. In this regard it has been argued that assessment may be a key feature. However, it is not simply the means and content of assessment that is important but its purpose: whether it is intended to inform learning directly, or whether it is intended for use outside the class. Whilst assessment should support not hinder teaching and learning, this is unfortunately not the current reality (Alexander, 2010).

G. Final conclusions

This section attempts to draw out key points from this paper to inform subsequent phases of this research project. These key points are presented through headings provided in guidance from the first deliverable (D2.1 – Guidelines for the background literature reviews).

G1. Emerging conceptual / contextual ground and any notable issues

G1.1 Epistemological ground

- *Cognition* - Embodied Cognition - Children's thinking is grounded in perceptual, social and emotional experiences. Children's thinking plays out in relation to the context/ environment. Context dependent and context independent thinking rather than concrete/abstract. While there has been growing recognition of the importance of affective factors, embodiment theories argue that it is not possible to separate thinking from perceptual and emotional experiences.
- *Socioculturalism* – cognitive development through children's participation in activities and practices of their communities – importance of relationships and cultural tools.

G1.2 Conceptual ground

- Early learning in science and mathematics and creativity have been discussed as independent discourses and fields of research. We need to consider also how these map onto each other and can be integrated.
- Need to distinguish – creative teaching, teaching about scientific creativity and developing children's mathematical/scientific creativity – we have tended to focus on the last category. Can teaching be creative if not promoting children's creativity? Does the meaning of creative change when referring to teaching?

G1.3 Background

- New research methodologies – greater awareness of children's early abilities in science and mathematics.
- Rationale for science and mathematics education in the early years – builds on children's concerns to investigate and explain the world

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from their earliest years, increased role of science and mathematics in young children's lives, importance of scientific literacy for citizens.

- Rights and responsibilities –the validity of children's alternative ideas in their own terms. Try to understand how they make sense to children and provide perspective turn taking to discuss and evaluate these.

G1.4 Learning themes

Physical interaction and expression

- Play – importance of play as a way for children to express their thinking and develop meaning. The need to consider the dynamic role of the teacher in scaffolding.
- Forms of expression – there is a need to develop children's language skills, particularly more specific scientific vocabulary as well as recognise and foster with a wider range of expression including gesture, visualisations.
- Out of class experiences – important to recognise the wealth of experiences children bring to class - how these can help give meaning to science and mathematics concepts and engage children. Also, as well as drawing upon, ways home experiences can extend thinking from school. Challenge of not exaggerating differences in children's opportunities at home. Maps well to informal / formal learning debates.
- Materials – potential of physical materials in nurturing curiosity and helping structure children's thinking as well as providing tools to foster dialogue.
- Digital opportunities – how to take advantage of new opportunities offered by new forms of interaction with digital technology for children to capture, share, discuss and evaluate ideas; whilst considering possible limitations (e.g. constrained interaction, initial skills required, lack of various sensory experiences such as touch, different home opportunities).

Communication

- Open questioning – need support children's understanding of open questions, by grounding in meaningful experiences or materials around children.
- Assessment – need to develop a more holistic approach to assessment that recognises children's attitudes and interaction with the environment and others in thinking. To consider the value of self and peer assessment.
- Collaboration - important to recognise community aspects of inquiry and creativity and support by scaffolding children's verbal reasoning skills with other children.

Processes of science and mathematics

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- Inquiry – consider inquiry as a lens through which to consider aspects of creativity (rather than juxtaposition of creativity with inquiry).
- Repertoire and choice of strategies – recognise the cognitive benefits of strategy variation.
- Nature of mathematics – support meaning by providing children with engaging opportunities to explore the value of mathematics in human culture e.g. why we count, why we use number symbols and the role of abstract models in mathematics.
- Explanation – need to build on children's early impetus to provide explanations to foster reasoning.
- Evaluation – it possible that children find evaluation of ideas more difficult than creation. This may be particularly significant as some discourses of creativity emphasise the generation rather than evaluation of ideas.
- Developments over time - importance of scope for ongoing exploration of themes within the classroom over time allowing opportunities for children to reflect, contribute, offer and develop own questions, ideas, and interests, for exchange within the classroom community.
- Metacognitive skills – need develop children's important skills e.g. executive control, attention.
- Innovation and transfer – how science and mathematics process skills transfer to different contexts – whether innovative thinking supports transfer.

G2. Issues and implications for CLS in area of literature review stating explicitly what research gaps exist

Whilst there remain many questions about children's learning, our knowledge has grown considerably in recent years and a number of themes do emerge as outlined above and in the body of the review. However, the challenges of drawing on insights from research to inform teaching are widely recognised. Furthermore there remains limited research that illustrates how these themes play out in practice in early years settings where a wide range of factors, such as curriculum structure, teachers' characteristics and school policy will be influential.

Examples of issues to consider:

- What skills / processes to scaffold
- The extent to which we should focus on the nature of science and mathematics
- Nature of connections between science and mathematics, opportunities provided by cross curricular approaches to learning and teaching in the early years.
- What types of materials and how these should be presented.

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- When to guide interaction and when to stand back
- Forms of questioning appropriate with young children that foster consideration of alternative ideas
- How productive collaboration between children can be fostered.
- How to capture multimodal, contextual assessment information that can identify progress and have external validity
- Ways of providing children with a framework for evaluating ideas
- Types of materials to help children externalise their thinking – and how to integrate e.g. talking about drawings
- How to identify teachers' beliefs and their relationship to practice

Connecting science, mathematics and creativity

- While creativity is major focus of rhetoric there is little detailed consideration in research or policy beyond broad messages.
- Dangers of stereotypes (traditional/creative teaching) – need more nuanced treatment – both Kind (Kind and Kind, 2007) and NACCCE.
- Connections to other discourses e.g. Well being, Personalisation.

G3. Issues and implications for CLS in respect of methodology including patterns of methodological approaches

Views of the purposes of science and mathematics education and perspectives on learning discussed in the review have implications both for the foci and conduct of research.

G3.1 Aims and purposes of mathematics and science education

As indicated above, we suggest a focus on opportunities for

- building on children's ideas and experience and curiosity
- promoting scientific literacy – emphasis not just on scientific knowledge but on developing skills and understandings related to the nature and processes of science.

These reflect value positions based on views of the purposes of education and of the nature of science and mathematics. Emphases vary across age phases and countries (as shown in the initial review of policy). The two strands identified can be seen as in opposition as reflected in ongoing tensions in primary education between child-centred, humanist philosophies and those informed by social and economic concerns (Shuayb and O'Donnell, 2008). However it can also be argued that scientific literacy is important for self-fulfilment and some suggest that addressing cognitive needs is important for self-actualisation.

G3.2 Epistemological perspectives

The review draws on research from a range of epistemological positions including Cognitive Constructivism, Social Constructivism, Embodied Cognition and Socioculturalism. In general terms the balance reflects a

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growing trend in the fields of mathematics and science education towards perspectives that locate the development of children's thinking within their immediate social and physical environment - as illustrated in the figure below from Alexander (2007).

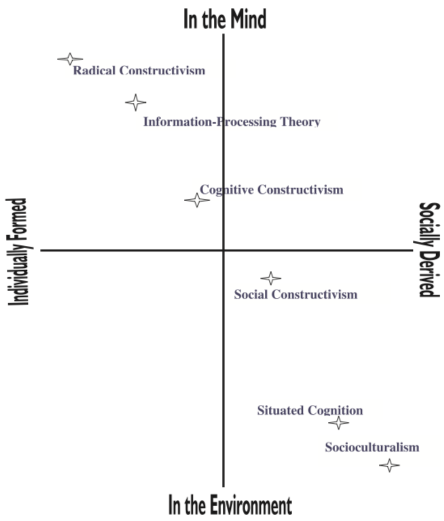

FIGURE 1 The epistemological positioning of learning theories.

(P. A. Alexander, 2007, p.68)

There is considerable debate about how far it is possible to bridge these perspectives (Alexander 2007). Driver et al (1994) argue that both personal and social perspectives on learning, as well as perspectives on the nature of science are necessary.

G3.3 Methodological approach

Rogoff's three foci of analysis (Rogoff (1987) cited in Robbins, 2005) provide a socio-cultural methodological tool, considering three aspects:

- personal, (focus on the child and what s/he is doing),
- interpersonal (interactions with peers, teachers) and;
- contextual (resources, physical arrangements, teacher beliefs, institutional factors)

G3.4 Discourse – frame of reference

Recurring themes in the review reflect these perspectives for example:

- Children as active agents
- Multimodal approaches – experience, expression, assessment
- Participation in a community of inquiry - collaboration
- Scientific argumentation and explanation
- Offloading thinking onto the environment
- Scaffolding – dynamic interaction between the teacher, materials and children

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G3.5 Research paradigm

- An interpretive research paradigm is appropriate given our concern to describe practices and understand perspectives of participants in their real world setting. It will be necessary, however, to draw out patterns that allow for comparison across contexts.

G3.6 Methodological issues and challenges

- Need to develop research approaches sensitive to capabilities of young children
- Will be developing and testing criteria and approaches to assess opportunities for learning and the potential for creativity – how to move beyond broad generalisation.
- How to involve young children in research processes.
- To gain a sense of teaching approaches and opportunities for learning will need to examine teaching over time – not just snapshot.
- Challenge of identifying/capturing contextual factors – these are recognised to have substantial influence. Need to explore range of contexts – what dimensions?
- What do we want /can we find out from questionnaire survey - approaches to gaining insights into teachers' views and practices (or really *about* practices). Approaches to teaching often implicit – finding ways to capture teachers' views and dynamic of teacher decision- making. Identifying national patterns.
- Recognise literature highlighting differences between teachers' stated beliefs and practice
- Notion of worked examples from practice to capture complex realities, potential for creativity in varied contexts.
- Devising teacher training materials and activities to support IBSE and creativity in mathematics and science that avoid a recipe approach, promote awareness of alternatives and teacher decision-making.
- Be aware of our own biases as researchers – consider possible limitations of creativity.

G4. Emergent relevant working definitions of key terms in the area of this literature review (4-6)

G4.1 Inquiry

Based on a review of research conducted between 1984 and 2001 Minner et al. (2009) argue that 'the term inquiry has figured prominently in science education, yet it refers to at least three distinct categories of activities—*what scientists do* (e.g. conducting investigations using scientific methods), *how students learn* (e.g. actively inquiring through thinking and doing into a phenomenon or problem, often mirroring the processes used by scientists), and a *pedagogical approach* that teachers employ (e.g., designing or using curricula that allow for extended investigations)'(:3).

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The US National Research Council defines inquiry as 'a set of interrelated processes by which scientists and students pose questions about the natural world and investigate phenomena; in doing so, students acquire knowledge and develop a rich understanding of concepts, principles, models and theories...and learn science in a way that reflects how science actually works' (NRC, 1996: p214) This makes connections between inquiry as a way students learn and what scientists do.

The definition provided by Linn, Davis and Bell concentrates more on what scientists do. However it also reflects key features of science proficiency highlighted in this review such as critical evaluation, considering alternatives, debating with peers, argumentation and explanation, also associated with creativity in science and mathematics.

Inquiry can be defined as 'the intentional process of diagnosing problems, critiquing experiments, and distinguishing alternatives, planning investigations, researching conjectures, searching for information, constructing models, debating with peers, and forming coherent arguments' (Linn, et al., 2004).

G4.2 Science processes

There is a range of processes involved in the linking, development and testing of ideas in science. Lists vary but common elements include (Russell and Harlen, 1990, p.16):

- '*Observing* –using all the senses, as appropriate and safe, to gather information about things in the environment, sequencing and comparing events, noticing similarities and differences between objects and events.
- *Interpreting* – bringing together information given or gathered so as to detect patterns or trends in it, make predictions or inferences based on any perceived patterns or draw conclusions.
- *Hypothesising* – proposing possible explanations of events or phenomena, particularly ones that can be tested by experiment, applying science concepts or ideas from previous experience to give alternative explanations that are consistent with the observed evidence.
- *Raising questions* – posing questions that can be answered by observation or investigation or that can be turned into an investigable question.
- *Planning* – identifying at least some of the steps and actions which have to be taken to solve a problem, to carry out an investigation or to collect evidence of certain kinds, recognising the variables that have to be controlled or changed or measured for a fair and appropriate test to be made.
- *Measuring* – quantifying observations so as to be able to say 'how much' using some standard or non-standard units, choosing and

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using an appropriate instrument and degree of accuracy for measuring for a particular purpose.

- *Recording and communicating* – making an oral or written report of observations, results, conclusions, expressing and being able to understand information in the form of graphs, charts, diagrams etc. as well as prose. *
- *Critically reflecting* – looking back on earlier ideas or what has been done in an investigation to suggest changes that would be improvements in future situations of the same kind, considering and evaluating alternative procedures and ideas.

*Communication is considered one of the essential elements of IBSE, that the learner communicates with audience(s) and justifies explanations (Assay and Orgill 2010 p.63).

Duschl et al. (2007) groups these processes into those associated with different phases in an investigation:

- *Generating evidence* – asking questions and formulating hypotheses, designing experiments,
- *Observing and recording*
- *Evaluating evidence.*

G4.3 Mathematical processes

Artz and Armour Thomas (1992) develop a cognitive-metacognitive framework identifying six categories in problem solving:

- read,
- analyse,
- explore,
- plan/implement, and
- verify.

In another framework, Mayer (Mayer, 1985) identifies four components of mathematics problem solving:

- translation,
- integration,
- solution planning, and
- execution.

These mathematical processes can be linked to science; indeed, various authors (e.g. Harlen, 1993) describe the relationship between science and mathematics, presenting mathematics as a grammar for science.

G4.4 Creativity

From the literature we propose the following definition of creativity (in relation to science and mathematics): 'generate alternative ideas and

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strategies as an individual or community, and reason critically between these'.

G5. Suggestions for research foci and possible research approach

CLS has the potential to

- Add to limited studies of policy and classroom practice in early years mathematics and science; Provide a means to examine the relationship between policy, research and classroom practice
- Identify common issues and trends across the consortium and any areas of notable difference
- Contribute a clear mapping between science and mathematics and the relationship to notions of creativity.
- Offer criteria and approaches for identifying/characterising learning processes in early years science and mathematics and the potential role for creativity
- To provide examples of the dynamic of learning and teaching and teacher decision making over time – that can be used in teacher education.
- Propose ways to capture important aspects of science and mathematics relating to creativity through assessment

Possible foci to be explored/compared as appropriate across WP3 (national policy and teachers' perspectives) and WP4 (school policy, classroom practices, teachers' and children's views)

Aims/purposes/priorities – learning objectives, teachers' views of aims and purposes – how these shift from pre-school to primary across the consortium – how they map on to 2.2 perspectives about appropriate aims linked to key strands of scientific proficiency and research evidence about children's capabilities, for example – emphasis on for children's questions, investigations, ideas and explanations – range of skills and processes promoted, links to IBSE.

Teaching and learning approaches including for example

- Kinds of activities undertaken – range and purposes ,balance of process/content/attitude (links to categorisations of types of activity in science and mathematics) – extent of child/adult direction
- Nature of teacher support/scaffolding – questioning, discussion, materials, staffing levels
- Forms of expression/recording including digital technologies – roles in learning
- Nature of collaboration between children – focus, purposes, how fostered?
- Assessment – forms of assessment, formative and summative

Contextual factors

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- Physical environment – provision, materials, space and its management indoors and out (or might be in contexts?)
- Range of Contexts for learning – role of cross-curricular approaches, connections to everyday life, science- related issues, use of the outdoor environment
- Teacher characteristics – training, qualifications, confidence, views of learning and teaching, range of guidance materials used to support planning/teaching/assessment processes
- Institutional factors – school policy/priorities, subject/phase specific expertise, opportunities for CPD
- Home–school – links with home, informal experiences.

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Appendices

Appendix A

Areas of expertise and Proposed allocation of responsibilities 30.10.2011

Key: Dark shading – proposed areas for initial focus for developing bibliography and associated rubrics

Grey shading – areas of expertise

1. RESEARCH	**GUF**	**UEF**	**UPJV**	**BG**	**IoE**	**UoM**	**EA**	**NILRP**	**UMinho**	**AUC**	**OU**
1.1 Aims for science and mathematics education											
Perspectives on nature of science and mathematics Goals of science and mathematics education											
Clarification of key terms											
1.2 Children's learning and development											
Approaches to studying young children's learning and development											
Skills and processes associated with inquiry											
Understanding of the nature of science and mathematics											
Conceptual development, conceptual change											
Attitudes *to* science/mathematics and *in* science/mathematics											
Informal learning											

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Active learning											
Links between science and mathematics											
Links to creativity in learning											

1. RESEARCH	**GUF**	**UEF**	**UPJV**	**BG**	**IoE**	**UoM**	**EA**	**NILRP**	**UMinho**	**AUC**	**OU**
1.3 Research into pedagogy in science and mathematics in the early years											
Approaches to research into pedagogy in science and mathematics in the early years											
Goals of science/mathematics education and models of learning - their implications for teaching											
Roles of exploration and investigation, role of wonder, fantasy link stories – reality), romance											
Roles of teacher - scaffolding processes, concepts, social interactions, promoting positive attitudes, differentiation zone of proximal development)											
Children's awareness of their own thinking, metacognition											
Social interactions with peers, roles of group work											
Communication in science and mathematics – varied modes, role of language, arts, ICT etc.											
Contexts - classroom environment physical, social, intellectual), making connections across the curriculum											
Approaches integrating science, maths, movement, language, ... integrated lessons, activities, ...)											
Issues of diversity, gender											

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Assessment practices and their impact on learning											
Teacher subject knowledge and attitudes, perception, interests											
Links between approaches in science and mathematics - attitudes, inquiry											
Potential for creativity in learning and teaching											

1. RESEARCH	**GUF**	**UEF**	**UPJV**	**BG**	**IoE**	**UoM**	**EA**	**NILRP**	**UMinho**	**AUC**	**OU**
1.4 Inquiry based science education IBSE)											
What is meant by inquiry based science education – international perspectives											
Learning about inquiry in mathematics and science, Learning through inquiry											
Skills and processes associated with inquiry											
Studies of inquiry-based science education in practice – insights, challenges											
Connections to creativity											
1.5 Nature of research approaches to maths and science education in the early years											
2 CURRENT PERSPECTIVES AND ISSUES IN POLICY AND PRACTICE											
2.1 Europe generally											

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Directions of travel in current policy – aims for science/mathematics education, approaches to learning, teaching and assessment include focus on IBSE)											
2.2 Perspectives from countries represented in the consortium											
Perspectives and issues in each country											
2.3 Approaches and issues in practice											
Common and contrasting themes and dilemmas across the consortium and more widely											
Potential to contribute to policy and practice across the EU											
3 KEY THEMES AND IMPLICATIONS FOR THE PROJECT											
3.1 Common themes											
3.2 Contrasting perspectives in research/policy/practice											
3.3 Issues and implications for CLS project – research questions and methodological issues											

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Appendix B

Rubric for Research articles

Creative Little Scientists Research Rubric (for research since 1990)

Full bibliographic reference (inc web links)	
Country / region (where research undertaken)	
Sample (i.e. size, age, group)	
Research questions (as stated or implied)	
Methodological approach (as stated in paper)	
Research methods	
Key findings	
Other comments	
Used in review? (Yes / No)	
Reasons for inclusion or exclusion	
Reviewer	

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Appendix C

Rubric for Policy articles

Creative Little Scientists Policy Rubric (for policy since 2000)

Full bibliographic reference (& web link if any)	
Country / region	
Date written	
Period this applied (emerging / current / previous)	
Status (Mandatory or Guidance)	
Age this relates to	
Key messages	
Other comments	
Used in review? (Yes / No)	
Reasons for inclusion or exclusion	
Reviewer	

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Appendix D

Template for Policy overviews

Creative Little Scientists: Task 2.2 Mathematics and Science Education
Brief overview of policy in partner countries/regions

Country/region
Age phase: Early Years – please indicate age range
Aims for science and mathematics education
Curriculum content – key topics, areas of study
Approaches to learning and teaching
Ways in which IBSE is promoted
Assessment approaches and formal assessment requirements
Key policy documents with dates (indicate if existing or emerging policy) - *include in bibliography and rubrics*
Any particular areas of current debate in policy/practice
References for papers that comment or offer a critical perspective on country/regional policy – *included in bibliography and rubrics*
Any other comments

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