Synergies between Inquiry-based Science Education and Creative Approaches

Arguably, whilst Inquiry-Based Science Education (IBSE) and Creative Approaches (CA) differ in their origins and developmental histories, they are also connected by underpinning influences. IBSE reflect the recommendations of Dewey who considered that there was an over-emphasis on facts without sufficient emphasis on science for thinking; in his model, the learner is actively involved and the teacher's role is as facilitator and guide. CA, whilst also influenced by Dewey's ideas about balancing children's interests with the curriculum, have been further shaped by recent studies of creative teaching and teaching for creativity. In both there is an emphasis on the learner, but in IBSE there is a greater emphasis on the role of the teacher in supporting the development of specific skills and understandings in science and mathematics. In CA, the role of the teacher is less subject-specific and may be more focused on developing learner creativity within and beyond the curriculum.

Both sets of approaches, which lie at the core of the project, are pedagogically associated with a range of child-centred philosophies from European and North American thinkers, including Rousseau, Pestalozzi, Fröbel, Owen and Isaacs, Steiner and Magaluzzi. These writers variously foreground the child as an active and curious thinker and meaning maker, and highlight the role of experiential learning. Both are closely aligned to Early Years education and theories of child development, but differ to some degree with regard to their expressed purposes, with IBSE focusing on questioning and the generation, justification and evaluation of ideas within a community. The expressed intent in CA is to help young people "believe in their creative potential, to engage their sense of possibility and to give them the confidence to try" (NACCCE, 1999:90). This might happen individually or in collaboration.

While there is a range of definitions of IBSE, as indicated earlier, a number of common emphases are evident including for example: the notion of authenticity in focusing on students' interests and issues relevant to their everyday lives (Hofstein and Lunetta, 2004); the central role of children's own questions as a context for inquiries (Drayton and Falk, 2001) and the importance of inquiry within a community, fostering a climate of discussion and debate with peers (Hmelo-Silver et al., 2007).

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Researchers of creative approaches highlight the role of innovation, originality, ownership and control (Woods and Jeffrey, 1996, Jeffrey and Woods, 2003) and recognise the need to encourage attributes such as risk taking, independent judgement, commitment, resilience, intrinsic motivation and curiosity. Additionally, curiosity, connection making, autonomy and originality have been documented as key features of the pedagogy and ethos found in the classrooms of highly creative professionals (Grainger, Barnes and Scoffham, 2006). Creative approaches are arguably open and applicable to a range of contexts and subject domains. In seeking to capture both creative teaching and teaching for creativity, Dezuanni and Jetnikoff (2011) view creative approaches as both the imaginative and innovative arrangement of curricula and teaching strategies in school classrooms and the development of students' creative capacities" (2011:264).

CA appear to include less emphasis on rational explanation and reasoned argument than IBSE, which tends to highlight reasoning and metacognition in relation to a focus on scientifically or mathematically oriented questions. Notwithstanding their different emphases, IBSE and CA are both interpreted and employed as tools for knowledge construction; they can be seen not only as ways of learning content, but also as motivational supports for the development of positive attitudes with regard to science, mathematics and creativity. Additionally, to different degrees both approaches appear to profile a number of pedagogical practices that seek to foster particular aspects of children's learning.

The common synergies identified were:

- **Play and exploration**, recognising that playful experimentation/exploration is inherent in all young children's activity, such exploration is at the core of IBSE and CA in the Early Years.
- **Motivation and affect**, highlighting the role of aesthetic engagement in promoting children's affective and emotional responses to science and mathematics activities.
- **Dialogue and collaboration**, accepting that dialogic engagement is inherent in everyday creativity in the classroom, plays a crucial role in learning in science and mathematics **and** is a critical feature of IBSE and CA, enabling children to externalise, share and develop their thinking.
- **Problem solving and agency**, recognising that through scaffolding the learning environment children can be provided with shared, meaningful, physical experiences **and** opportunities to develop their creativity as well as their own questions and ideas about scientifically relevant concepts.

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- **Questioning and curiosity**, which is central to IBSE and CA, recognising across the three **domains** of science, mathematics and creativity that creative teachers often employ open ended questions, and promote speculation by modelling their own curiosity.
- **Reflection and reasoning**, emphasising the importance of metacognitive processes, reflective awareness and deliberate control of cognitive activities, which may be still **developing** in young children but which are incorporated into Early Years practice, scientific and mathematical learning and IBSE.
- **Teacher scaffolding and involvement**, which emphasises the importance of teachers mediating the learning to meet the children's needs, rather than feel pressured to meet a given curriculum.
- **Assessment for learning,** emphasising the importance of formative assessment in identifying and building on the skills attitudes, knowledge and understandings children bring to school; supporting and encouraging children's active engagement in learning and fostering their awareness of their own thinking and progress.

Play and exploration

Whilst pre-school children differ with regard to their experience of play, exploration and interaction, the significance of play in early learning is widely recognised and represents the focus of considerable research within both approaches. It is argued that informal playful experiences nurture children's motivation to understand their world, (Larsson and Halldén, 2010) and Gopnik, Sobel, Schulz, and Glymour (2001) claim that children as young as two are able to make causal inferences about information they gain from the environment, demonstrating an ability to reason and reach conclusions, although not necessarily verbally. The environment affords significant opportunities for scientific learning through play, indeed in Reggio Emilia pre-schools, which often involve young children playfully investigating the environment, the power of play is evident (Edwards, Gandini, and Forman, 1993), and research by Garaigordobil and Buerrueco (2011) suggests that sustained play in Early Years settings increases children's creativity.

In seeking to interrogate the similarities between play and learning in the Early Years, Samuelsson and Carlsson (2008) comment that "pedagogy should not separate play and learning but draw upon the similarities in order to promote creativity in future generations" (2008:629). They suggest the similarities include: children's experience as a point of departure, discernment, simultaneity and variation as well as meta-cognition, meta-cognitive dialogues and meta-communications. A Finnish case study of pre-school teachers, further underscores the idea that play and child-initiated activities characterise the pedagogical work of teachers of this age group

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(Einarsdottir, 2003). Most scholars appear to perceive that playful experimentation/exploration is inherent in all young children's activity; such exploration is at the core of IBSE and CA in the Early Years. Poddiakov (2011) asserts there are two main types of experimentation in the classroom which teachers need to foster – 'personal experimentation [mental]', aimed at discovering relations and the quest for new knowledge and 'utilitarian experimentation [physical]' aimed at solving practical tasks. Poddiakov also proposes a third 'special' type of experimentation 'social experimentation', which he suggests involves trying out forms of behaviour.

Many empirical studies within the wide field of science, mathematics and creativity research which were examined in the literature reviews which supported the Conceptual Framework, suggest that open-ended exploratory contexts are well suited to fostering learner creativity and learning in science and mathematics (Jeffrey, 2004; Burnard et al., 2006; Bonawitz et al., 2011; Cremin et al., 2006; Einarsdottir, 2003; Fawcett and Hay, 2004; Poddiakov, 2011). Supported by the pedagogic space and scope offered for exploration, it appears that children in these studies often extended boundaries and explored with interest and commitment. The young learners' affective engagement in this 'third area', as Winnicott (1971) calls the deep play of childhood, appeared to prompt an openness that their teachers frequently sought to build upon. Such openness, alongside objectivity, is recognised as a critical feature of the development of a scientific stance or attitude (Feng, 1987).

According to Goswami and Bryant (2007) pretend play contexts, which prompt children's imaginative engagement, enhance their thinking, reasoning and understanding of concepts, although they argue that scaffolding by an adult is required if these are to be effective for learning in school. Edo et al. (2009) found that structured sessions and educational visits between free play sessions helped focus the children on the mathematical elements in their role-play. In a not dissimilar manner van Oers (2010), notes that parents, in reinterpreting children's verbalisations in play, are able to 'mathematicise' play, capitalising on opportunities for learning mathematics in such contexts.

Several studies which can be seen to involve examination of IBSE and CA, albeit implicitly, demonstrate the importance of providing children with sufficient time and space to foster such exploration and creative thinking (e.g. Cremin et al., 2006; Jeffrey, 2005; Martin and Schwartz, 2005). The provision of 'stretchy' time in the possibility thinking studies encouraged children's immersion in extended playful activities and, alongside the enriched and mutually owned space, appeared to motivate and involve the young thinkers (Cremin et al., 2006). In the European CLASP project, Jeffrey (2005) also noted that considerable time was afforded to 'open adventures',

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and that these exploratory opportunities enabled the young to experiment, push boundaries and take risks. Additionally, though somewhat differently, Metz (1998) argues that in relation to developing scientific concepts through investigation, over time children improve strategies, and shift in emphasis from making things happen to developing their understanding. This need for time to support exploration is also emphasised by Glauert (2009a:46), who proposes that over time children ”may begin to raise questions for investigation, look for patterns and relationships and offer explanations”.

In promoting opportunities for exploration in the Early Years, research in science, mathematics and creativity also highlights the importance of a rich physical environment, use of the outdoor environment and the importance of making links with children’s everyday lives to engage interest and foster curiosity (French, 2004). Furthermore provision of a wide range of materials in the classroom can be motivating and offer different ways for young children to represent ideas and express their thinking.

2.2.1.2 Motivation and affect

Research in science, mathematics and creativity indicates that play based exploratory contexts afford rich opportunities for supporting the development of both positive attitudes and motivation; which as noted earlier are key constructs of the affective domain in science education (Koballa and Glynn, 2008) and arguably mathematics. Based on the Experiential Education project, Laevers (2000, 2005) argues that the creation of playful learning contexts which foster deep learning is at the core of quality early education which he posits is affectively engaging and “affects the deeper structures on which competencies and dispositions are based” (2000: 20). Early Years science and mathematics teachers are seen to make learning relevant and engaging by incorporating children’s prior-knowledge and embedding activities into the children’s everyday experiences, this, it is argued, makes it easier for children to state their own opinions and work imaginatively with the tasks given. Moreover, it is suggested that stressing the relevance of science through issues based on hands-on experience can help children start to see connections between science and their close surroundings which it is argued acts as a motivating factor (Kobolla and Glynn, 2008; Kramer and Rabe-Kleberg, 2011).

Other work has also highlighted the role of aesthetic experience in promoting children’s affective and emotional responses to science and mathematics activities. Milne (2010), for example, argues that fascination, engagement, awe, wonder and interest can prompt aesthetic engagement, spark children’s curiosity and lead to the use of scientific inquiry to develop explanations of phenomena. Devlin (2000) also argues that experimentation, guessing and connecting to personally relevant real life

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issues can encourage young mathematicians. The affective dimensions of science learning which have received less attention by researchers than the cognitive dimensions, is not, Perrier and Nsengiyumva, (2003:1124) argue, just a simple catalyst, but "a necessary condition for learning to occur". Certainly creativity research highlights the importance of engaging children affectively and emotionally (Woods, 2001; Woods and Jeffrey, 2009) and others also highlight that utilising the widely recognised power of narrative and dramatic story making, can make learning relevant by engaging children imaginatively and thus fostering their creativity in different domains (Bruner, 1986; Craft et al., 2012; Cremin et al., 2006; Paley, 2001; Sawyer, 2004a, 2004b). The role of narrative as a playful imaginative context in which young children's creativity can be nurtured is an area for potential exploration in science and mathematics; and has begun to be explored in the creativity literature (Cremin et al., 2012).

Dialogue and collaboration

Another area of synergy between the research literatures focused on creativity and on IBSE in science and mathematics is the significance of dialogue and collaborative learning. It is widely accepted that language plays a crucial role in learning in and through science (Carlsen, 2008; Roth, 2007), and communication is seen to be one of the critical features of IBSE, although other modes of communication also enable children to externalise, share and develop their thinking (Glauert, 2009b). Listening to children's initial ideas is important not only to afford respect, but also to emphasise the validity of alternative points of view (Coltman, et al., 2002), their perspectives are not simply misconceptions. In school, IBSE involves problem solving activities with peers, which are often highly collaborative, and affords children access to a wider range of problem-solving strategies.

The process of explaining their thinking verbally can help children consolidate their ideas (Chi, De Leeuw, Chiu, and Lavancher, 1994) and enable them to develop their verbal reasoning skills (Mercer, Wegerif and Dawes, 1999). Such skills are seen to be essential for learning in science and mathematics. The communication of ideas and ways of thinking allows children to listen to others' strategies and ideas and develop increased awareness which may prompt a desire to restructure their own ideas, in the face of other more plausible or consensual ones (Varela, 2010). This links to research on the value of developing children's metacognitive awareness. Although little of this work is focused on the Early Years, it does suggest that if children are afforded opportunities to explore and work in small groups, this may make them more attentive to their own thoughts and the thoughts of others, encouraging monitoring and self-regulation (Larkin, 2006; Littleton et al., 2005).

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Much creativity research recognises that creative processes are essentially social and necessarily collective and collaborative (e.g. John Steiner, 2000; Littleton and Mercer, 2013; Sawyer, 2006) and there is considerable work exploring the nature of creative dialogue which indicates that dialogic engagement is inherent in everyday creativity in the classroom (Littleton et al., 2005; Mercer and Littleton, 2007; Rojas-Drummond et al., 2006; Vass, 2007; Wegerif, 2005). This body of work, much but not all of which orients around the 'Thinking Together' programme, demonstrates that children may benefit from support in developing their collaborative reasoning, and when supported are able to engage creatively. Mainly undertaken in upper primary classrooms, this work reveals inter-subjective co-construction and collaboration in the context of shared social ground rules in the most successful creative dialogues. Howe et al. (2007) also show how extensive training in generic group skills can lead to increased collaborative learning and new knowledge. Additionally, in order to support the development of children's reasoning in primary science lessons, Naylor et al. (2007), show that the use of puppets can help to engage and motivate children, promote talk that involves reasoning, and encourage the involvement of reluctant speakers. Collectively, these studies suggest that children of all ages may need support in developing their capacity for dialogue and collaboration that enhances their reasoning skills.

However, even in the absence of teacher guidance and the use of ground rules, puppets or training, on the basis of other studies it is claimed that children are able to construct an argument and appreciate alternative viewpoints (e.g. Naylor et al., 2007). Also that without the presence of a teacher, there are benefits to unstructured group discussion (Kramer and Rabe-Kleberg, 2011). In analysing the findings from a German project entitled 'Haus der Kleinen Forscher' (the House of Little Scientists), which sought to enhance the technological, mathematical and scientific education of preschool children, Kramer and Rabe-Kleberg (2011) note that open discussion in problem solving contexts without a teacher appeared to nurture creativity. They document two main forms of group interaction: constructive, creative interaction and competitive interaction. Reminiscent of Mercer et al.'s (1999) category of 'disputational talk', the latter was less productive, however the former, which occurred when the children were able to experiment collaboratively with one another relatively free from constraints, appeared to nurture creativity. In their interactions without their teacher, the young children's collaborations often displayed creativity and also fostered their effective task-management and scientific understanding. Kramer and Rabe-Kleberg (2011) argue that as the young learners actively applied their knowledge to creatively solve problems they enhanced their understanding of scientific processes. On the basis of this study, they identify two criteria that they claim are necessary for efficient and creative work: open dialogue between children

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and the teachers, (so that children learn to express and discuss their own ideas) and enough space/opportunities for the children to experiment and work on their own or in peer groups.

Problem solving and agency

Related to the common focus on dialogue and collaboration are the data around the identification of problems and group problem solving which is a central part of IBSE (National Research Council, 2000) as well as widely recognised within CA to education. As discussed by various authors defining inquiry based teaching approaches can be problematic, in particular there is considerable debate about the role played by the teacher in constraining or affording learner agency (Asay and Orgill, 2010). In an attempt to identify approaches to inquiry that can foster creativity, Barrow (2010) maps the five learner attributes of inquiry identified by the US National Research Council to a dimension of more or less student directedness or agency (see Figure 2.1 below). Barrow discusses how this scale reflects teacher approaches that range from student-directed open inquiry approaches, to a guided inquiry approaches, and ultimately teacher directed 'cookbook' approaches.

Barrow's work highlights that the extent of children's agency in inquiry approaches is often unclear. Indeed, in a critique of inquiry and problem based approaches, Kirschner, Sweller, and Clark (2006) argue that such approaches disregard evidence of the limitations of guidance during instruction. This criticism is contested by Cindy, Duncan and Clark, (2007) who argue that inquiry approaches actually involve a high level of scaffolding. There are debates therefore in the literature concerning the role of the teacher in IBSE, and the extent to which teachers are able to scaffold young children's problem finding and solving without hindering their agency. In this regard, it is helpful to consider the role the teacher can play in providing children with materials and activities, to foster shared and meaningful experiences. This reflects greater recognition of a more holistic approach in early learning that considers the physical, social, and affective context in meaning-making (Duit and Tregust, 2003; Glauert, 2005 Goldin-Meadow, 2009; Beghetto and Kaufman, 2007; Chappell, 2008).

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Essential Feature	Variations			
Learner engages in scientifically orientated questions	Learner poses a question	Learner selects among questions, poses new questions	Learner sharpens or clarifies question provided by teacher, materials or 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 analyse	Learner given data and told how to analyse
Learner formulates explanations from evidence	Learner formulates explanations after summarising 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 given all 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 gives steps and procedures to communication
More <------------ Amount of Learner Self-Direction -------------> Less				
Less <---------- Amount of Direction from Teacher->Material More				

Figure 2.1: Essential features of classroom inquiry and their variations (Barrow, 2010: 3)

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Structuring the learning environment appropriately can give children space and agency to explore problems. Indeed, research has shown that, given the opportunity, children will independently vary their problem solving approaches over time (Siegler, 1987). Moreover, children are often competent in identifying efficient strategies for solving problems. This is important considering the role that cognitive flexibility has been attributed in learning and creative problem solving (DeHaan, 2009). The flexible use of different strategies by more competent learners has been shown in various mathematical problems (Gray and Tall, 1994; Torbeyns, Verschaffel, and Ghesquiere, 2002). This process of exploration tending towards more efficient strategies has also been articulated by Martin and Schwartz (2005) in their theory of Physically Distributed Learning. They demonstrate 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. Whilst several studies highlight the benefits of encouraging children to generate and evaluate possible strategies, it is possible that this may detract from time spent practising / becoming familiar with domain specific strategies. Schwartz, Bransford and Sears (2005) refer to this as the trade-off between 'innovation and efficiency'. In discussing the cognitive benefits of innovation, they propose that 'optimal learning' is a balance between the two. Their work refers to learners of all ages, so it is possible that the benefits of generative thinking are more pronounced for young children.

Providing children with shared, meaningful, physical experiences can therefore provide them with opportunities to develop their own questions as well as ideas about scientifically relevant concepts. In other words, by scaffolding the learning environment, it is possible to foster children's agency in problem finding and solving. As highlighted by Fleer (2009), teachers play a fundamental role in mediating children's thinking between everyday concepts gained through playful interaction and more formal scientific concepts.

In the creativity research literature it is also evident that problem finding and problem solving are core elements and that engagement with problems can foster child agency, ownership of learning and the development of self-determination and control (Craft et al., 2012; Cremin et al., 2006; Cremin, Barnes and Scoffham, 2009; Jeffrey, 2005; Raggl, 2006; Sugrue, 2006; Woods and Jeffrey, 1996). These studies collectively suggest that children's creative engagement in finding their own problems, problems that they wish to explore or solve is central to creativity, and links closely to their curiosity and questioning stance examined earlier. Additionally, teachers' trust, interest and respect for children's questions facilitates young people's sense of autonomy and the degree to which they are in control of their own learning. Rather than leading, the teachers in these various creativity studies often set open ended tasks

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which the children undertook in groups or pairs and which they organised themselves, following their own ideas and interests as collaboratively engaged problems solvers, or in the case of Craft et al. (2012) practitioners passing the problem back to the learners to foster their decision making and agentic actions. McWilliam (2008) however in acknowledging that for decades teachers have been expected to position themselves as ‘custodial risk minimisers’, suggests that they have potentially limited the autonomy and agentic space offered to children.

Questioning and curiosity

The role of questions, both children’s and teachers’ is another common area of research across these interrelated fields and is recognised as central within both IBSE and CA. Whilst it is widely accepted that young children are innately curious and seek to explore the world around them, Nickerson (1999) suggests that the educational process can both inhibit and stifle their curiosity, their impulse to question and their engagement in mental play. Some studies indicate that teachers who use a lot of questions achieve high levels of pupil involvement and promote learning (Rojas-Drummond and Zapata, 2004), while others suggest that creative teachers often employ open ended questions, and promote speculation by modelling their own curiosity (Craft, 2002; Cremin et al., 2009; Robertson, 2002). Arguably, they make use of open questions to promote deeper, transferable thinking and to invite learners to engage with problems of relevance. With upper primary learners in science and mathematics, this can, it is claimed, improve standards of understanding and knowledge through increasing metacognition (Shayer and Adey, 2002).

In contrast, Harris and Williams (2007) show that if young children have little experience of open questions at home, they may find such questions difficult. These researchers suggest that rather than focusing on open and closed questioning, it may be preferable 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) and how teachers might use resources or gestures to help ground questions to support children’s thinking.

The role of the context in questioning is also important in considering children’s own questions. As discussed in the previous section, younger children in particular may need time, and space to explore materials in order to formulate ideas and questions (Glauert, 1996). Moreover, it is important to consider that children’s curiosity may not be expressed verbally, but through other modes. Children’s drawing, gestures, or even actions with materials may illustrate the focus of their investigation; attending to these other modes can provide teachers with means to build upon the different ideas children are exploring, indeed studies that foreground children’s visual representations have been seen as an entry point to their creativity since the 1940s and are still in use today (Uzsynka, 1998) including ‘gestalt holistic assessment’

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introduced by Brewer (1989) and subsequently developed by others (Nelson et al., 1998) who used the technique to examine the relationship between chronological age, children's rated-drawing ability and their scientific knowledge. Children's 'intellectual play' is explored through their visual representations by Wood and Hall (2011) and Stevenson and Duncum (1998).

When considering creativity in the classroom, it is important to consider differences between different domains and the potential tensions that may arise when considering how broadly we wish to encourage children's thinking. In mathematics, for example, how beneficial is it to encourage children to question and consider alternative symbols or vocabulary? In science, might there be risks in children's sharing personal explanations that may detract other children's attention from particular science concepts? It is important therefore when discussing 'open questioning' to consider how questions are interpreted by children and how this may help them reflect on particular concepts. In science Harlen and Qualter (2004) draw attention to the different kinds and purposes of questioning for example whether they are person or subject centred, open or closed, 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. This is supported by Chappell et al.'s (2008) work, which identified that questioning of different kinds and for different purposes can act as a support to children's inquiries and learning.

Finally, it is important to consider how the teacher can model and foster positive attitudes to curiosity and questioning. Teachers who show their own creativity by constantly questioning themselves and thus profiling self-reflection are well placed to foster such attitudes in others, thus potentially generating new questions on the part of the learners and 'developing intrigue' (Poddiakov, 2011), a core capacity of young scientists.

Reflection and reasoning

In terms of reflection and reasoning, there is rather more in the science education research literature evidencing the importance of these skills within IBSE than in CA. IBSE seeks to help children make use of 'data' from home, school and community experiences. However, this requires understanding of the relationship between evidence and theory linked to the nature of science, with which children, Metz (2004) argues, have difficulties as they are biased towards interpreting evidence in terms of their existing theories and will not develop scientific reasoning automatically from experience. In coordinating theory and evidence, Kuhn (1989) emphasises the importance of metacognitive processes: reflective awareness and deliberate control of cognitive activities. This may explain younger children's difficulties as their metacognitive abilities are still developing. Goswami and Bryant (2007) identify four forms of infant learning mechanisms: statistical learning (neural structures from

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patterns of observed events); learning by imitation; learning by analogy; and causal learning. They argue causal or 'explanation-based' learning is present in infancy but that 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 the evaluation of hypotheses (Kuhn, 1989). Arguably this relates to conceptions of creativity that focus upon the generation and evaluation of ideas, but there is little explicit discussion in the creativity research literature on the role of reflection in the Early Years. Although the Reggio Emilia schools profile children's reflection and documentation of their learning, this is not always seen through a creativity lens (Malaguzzi, 1993; Rinaldi, 2006), though more recently colleagues in the UK working within more overtly creative approaches have begun to analyse the process of evaluation and thus reflection (Bancroft et al., 2008).

In the context of IBSE it is argued that participating in the processes of sharing, testing and then evaluating ideas can foster an appreciation of scientific argumentation and explanation. The teacher has a key role to play here in promoting a supportive climate for debate, questioning, feedback and critical reflection. Research suggests that children as young as six can understand the goal of testing a hypothesis, and can distinguish between conclusive and inconclusive tests of that hypothesis in simplified circumstances (Sodian, Zaitchik, and Carey, 1991). It has also been shown that children have an early 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, 1989).

There are important roles for expression and recording in different modes in encouraging reflection and evaluation of ideas, strategies and learning and providing a basis for discussion and dialogue with others. This may take many forms: children's drawing (Barnes, 2001; Heath and Wolf, 2005; Stevenson and Duncum, 1998; Wood and Hall, 2011); their writing and text-making (Armstrong, 2006; Chapman, 1995; Pahl, 2007); questioning assumptions, redefining problems and considering what else might be possible (Richhart, 2002); and may involve the use of digital technologies. Children's creativity is revealed through these means as well as their understandings. In exploring creativity in science in the Early Years, Wollman-Bonilla (2000) for example showed how even very young children would change their writing styles to suit instructional, recount of events and fictional narratives. This may be considered creative when considering Pahl's work (2007) who has suggested that children's abilities to bring a number of different experiences into one coherent piece of text is an indicator of creativity in young children. In whatever form children have expressed

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their ideas, the teacher in focusing the young learners' attention on how they think about something, fosters the child's meta-cognitive awareness and helps to make the implicit more explicit. In a study exploring the science of forces, a teacher, who profiled reflection and questioning, noted that the metacognitive capacity of the 6-7 year olds in her class far exceeded her expectations; their ability to engage in metacognitive dialogues about their learning and to make creative metaphorical comparisons was marked (Williams and Cremin, 2008).

In mathematics, two studies profile the value of children becoming aware of their own cognitive practices, with Schoenfeld (1987) arguing metacognition involves: knowledge; self-awareness (self-regulation); and beliefs and intuitions. Wellman and Lagattuta (2004), focusing on the relationships between theory of mind, learning, and teaching, suggest that children's psychological explanations are central to formal school-based teaching and learning. They posit that psychological explanations are frequently required in schooling, providing "an important platform for logical-explanatory reasoning" (2004:491). Thus, encouraging children to provide explanations and to evaluate and comment on other's mathematical explanations is important, in order for them "to understand the explanations and reasons for various phenomena and procedures" (2004:492). In contrast, children's metacognitive awareness of their own creative thinking in the Early Years has not been widely researched.

The complex synergies between science, mathematics and creativity in Early Years education are conveyed diagrammatically in Figure 2.2, which seeks to highlight the dynamic relationship fostered by the teacher, in particular through scaffolding young children's learning.

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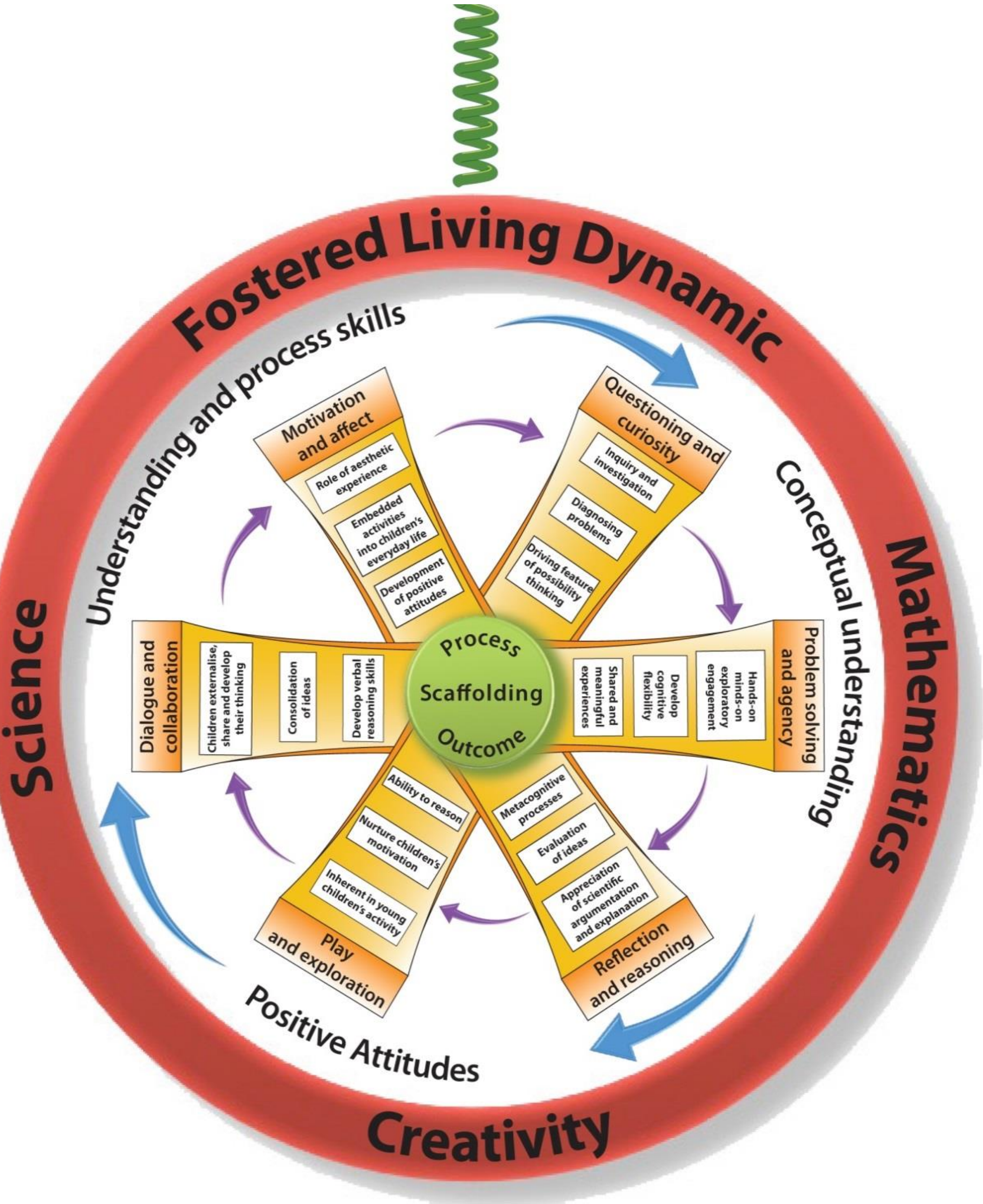

Figure 2.2: A diagram to represent the pedagogical synergies between creativity, science and mathematics in Early Years education

Teacher scaffolding and involvement

Notwithstanding the recognition that IBSE and CA both include attention to problem solving in exploratory contexts, in which questions, collaboration, motivation and reflection play a significant role, the efficacy of these approaches depend largely on the teacher's role in scaffolding children's learning. Scaffolding has been considered

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beneficial for young children fostering their independence as inquirers and problem-solvers (Rittle-Johnson and Koedinger, 2005; Metz, 2004), their creativity as possibility thinkers (Cremin et al., 2006; Craft et al. 2012), their conceptual knowledge (Coltman, Petyaeva and Anghileri, 2002), and their strategies (Secada, Fuson and Hall, 1983), and meta-cognitive strategies (Aleven and Koedinger, 2002).

However, studies of scaffolding in varied contexts indicate the complexity of the issues involved in relation to the context and purposes of activities. For example, in a quasi-experimental study undertaken with pre-schoolers in a science museum, Bonawitz et al. (2011) investigated the implications of explicit instruction on exploratory play. It could be argued such instruction should scaffold learning and enrich their creativity, yet this research suggests that teaching children in this way constrains their exploration and discovery, since even the children not being explicitly taught in this context, extended their assumptions from overhearing adults' comments and demonstrations to other children, and adapted their behaviour accordingly. As a consequence, the researchers suggest that such "pedagogy promotes efficient learning but at a cost: children are less likely to perform potentially irrelevant actions, but also less likely to discover novel information." (2011: 322). Their work on the 'two-edged sword of pedagogy' has considerable implications for the project, and suggests for example that delaying instruction until the learner has had a chance to investigate and inquire on their own or with others could promote innovation and discovery.

In the study of the 'House of Little Scientists', Kramer and Rabe-Kleberg (2011), in observing teachers and children during their work on a scientific problem, identified two types of teachers' behaviour which emerged naturally: 'ignoring' and 'integrating' interaction with children. The former behaviour involved teachers paying little attention to the children's ideas and approaches; they tended to tell the children how to do the experiment 'in the correct way'. In contrast, the occasions on which teachers showed more 'integrating behaviours', they tried to incorporate the children's views and foster self-directed inquiry. However two distinct forms of children's reactions to their teachers' behaviour were noted: in the former when their ideas were 'ignored' the children worked together to try to find answers and 'crossed new frontiers' being open to new ideas/approaches, in the latter they sought to conform to the teachers guidance and exercised less agency and problem solving.

This issue of teacher positioning relates to the 'standing back' strategy (Cremin et al., 2006) as part of CA. What distinguishes this strategy is the position of the teachers, who prioritise stopping and observing, and listening and noticing the nature of the learner's engagement. By being 'one remove' yet highly attentive, the teachers, it is claimed, were able to notice any unusual or unexpected actions, behaviours or ideas suggested or enacted by the children. Whilst the teachers in the 'House of Little Scientists' study, 'stood back' for other reasons (often due to lack of assurance and

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scientific knowledge) the effect appears to have been the same – the young children were able to take up positions both as decision-makers and agentic learners, utilising the time and space made available for them to explore and experiment. The work of other scholars also highlights the pedagogic practice of respecting children sufficiently to stand back from their endeavours in order to observe their interests, needs and direction of learning and then build upon this (Fawcett and Hay, 2004; Rinaldi, 2006; Tobin, Hayashi and Zhang, 2011). This suggests that for IBSE and CA to foster creativity and problem solving requires professional restraint and well developed skills of close observation. Hyvönen (2008) too highlights the role of teacher as 'allower', implying some degree of standing back and avoiding too much intervention, though she also mentions other roles: leader, afforder, coordinator, supporter, tutor, motivator and facilitator.

In articulating their theory of early developmental pedagogy, Samuelsson and Carlson (2008) argue that one of the main features is the teacher focusing the child's attention towards problems that arise. They suggest that at times the teacher is more fully and playfully involved as a fellow collaborator and provocateur. This connects to McWilliam's (2008) conception of the 'meddler in the middle' and involves the teachers in working alongside children with intense sensitivity as to appropriate interventions. This positioning of the teacher as a fellow artist or at least fellow collaborator engaged in co-authoring is in contrast to more traditional notions of power relationships in the classroom. Although in Early Years education the hierarchical model, more common in later primary and secondary education, is less prominent (Smidt, 2006), there is still scope for a closer examination of teachers positioning in IBSE and CA.

The challenge for teachers then is to achieve a balance between structure and freedom in Early Years educational settings, adopting a more dialogical pedagogical model in which the teacher orchestrates standing back with collaborative intervention in science and mathematics classrooms.

Assessment for learning

There is a central role for formative assessment in a responsive approach to teaching involving identifying and building on the skills attitudes, knowledge and understandings children bring to school; in supporting and encouraging children's active engagement in learning and fostering their 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.

In the Early Years there are also arguments that a more holistic approach to assessment is important, that takes account of children's attitudes and interaction with others and with the environment in thinking (Glauert, 2009b). Insights from recent

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research highlight the need to develop assessment approaches sensitive to the capabilities of young children (Robbins, 2005). Calls have been made for the development of multimodal approaches to assessment in early mathematics and science activity (e.g. Glauert, 2009a) that attend to, for example, children's gestures, speech or visualisations, and digital technology offers increasingly holistic ways of capturing children's engagement. Similarly within creativity, efforts have been made in the last two decades toward understanding and assessing creativity as complex (Feldhusen and Ban, 1995), involving multiple components (Amabile, 1983). In the context of the Early Years this has meant an emphasis on children's learning in context, close observation and documentation, sometimes from multiple perspectives (Rinaldi, 2006, Project Zero and Reggio Children, 2001).

The assessment of creativity is an area of growing interest, as creativity and innovation are perceived as increasingly important globally. The EU has paid attention to the assessment of creativity since the 2009 European Year of Creativity and Innovation which included a conference on the measurement of creativity held in Brussels, later published by the Joint Research Center, European Commission (Villalba, 2008, 2009). Hingel (2009) argued as part of this EU exploration of the potential for measuring creativity, that measures should be developed to provide evidence of progress over time.

Whilst formative assessment for learning is vital in helping diagnose appropriate next learning, there remains an emphasis in policy on the role of summative assessment for wider comparative purposes and its use for evaluation of performance at school, national and international levels. International comparisons in particular are driving national and European concerns to document and nurture economic competitiveness. This can be seen within schemes that seek to document the learning of older learners, for example in the IEA[1]'s Trends in International Mathematics and Science Study (TIMSS[2]) for grades 4 and 8 introduced in 1995 and the OECD[3]'s Programme for International Student Assessment (PISA) for fifteen year olds, introduced in 1997. Each of these large scale assessments systems provide comparative summative assessment information of older learners for educational policy making purposes and have rapidly gained international governmental support. TIMSS encompassed more than sixty countries in 2011. In the case of PISA, 65 countries and economies were involved in the 2012 wave. Both produce summative data through specially administered tests. Whilst TIMSS focuses on mathematics and science, PISA offers an interesting blend. Since PISA sets out to measure knowledge and skills seen as vital to living as an effective 21st century citizen, its focus is not only on the domains of knowledge seen as vital in participating countries, but also on appropriate skills

1 International Association for the Evaluation of Achievement
2 TIMSS was linked with PIRLS (Progress in International Reading Literacy Study) in 2011
3 Organization for Economic Cooperation and Development

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(Schleicher and Tamassia, 2003). Thus since 2003, problem-solving has been assessed within the context of using science and mathematics knowledge to solve everyday problems as part of the PISA assessment framework.

The inclusion of problem solving highlights increasing concern within Europe to find ways of measuring complex skills in relation to traditional domains of knowledge, and work undertaken by OECD has also recently focused on the development of a composite indicator for creativity (Saltelli and Villalba, 2008). There is a clear recognition of the need to move beyond the pure acquisition of knowledge in the ways that education systems evolve (Stewart, 2011). What is not yet in place is a way of assessing creativity in the context of other subjects such as science and mathematics, and it is not clear how this might develop; the European Commission's Joint Research Centre probe was sceptical about the cost and effectiveness of using PISA or another international test (Villalba, 2008:33).

Thus internationally the tension between formative and summative assessment in relation to assessment for learning vs assessment for comparative purposes, is evident. Summative assessment is being used as a powerful tool for policy makers to know how children are doing, and to compare countries' performance. Arguably, these large scale surveys are used to aid policy development, ensure preparation for adult life and influence national growth rather than formatively guide individual progress or development. It is possible, as Saltelli and Villalba (2008) argue, that measurement of creativity is vital in that the comparison between countries' performances may provide insight into how key variables interact at a wider societal and economic level – for example, how the rise of the 'creative class' might relate to economic growth. They argue that a European creativity indicator should be developed – a challenge taken up by Kern and Runge (2008) who grouped thirty-two indicators for creativity which focus on social and economic factors, although the establishment of an intercultural notion of creativity is not yet under way (Hingel, 2009).

It should be noted that the summative use of assessment for comparative purposes is highly economically-focused, seeing creativity as a means to the ends of economic prosperity; an assumption that can be challenged as discussed earlier (Gibson, 2005). Not only that, but as Looney (2009) notes, writing for OECD, there is a tension between high-stakes summative assessment and innovation. Looney argues that it has been possible to reconcile such testing through a range of strategies encompassing performance measurements for students and schools, re-aligning standards and assessment and integrating assessment and learning, and perhaps most importantly through staff taking appropriate risks to foster creativity and innovation in their institutions.

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