CREATIONS Developing an Engaging Science Classroom	**D2.1 The features of inquiry learning: theory, research and practice**

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Project Reference:		**Editing:**	Chappell, K., Hetherington, L., Ruck Keene, H., Slade, C., Cukorova, M.
Code:		**Approved by:**	
Version & Date:	**FINAL**	**Process Owner:**	

Short Description:

CREATIONS aims to demonstrate innovative approaches and activities that involve teachers and students in Scientific Research through creative ways that are based on Art and focus on the development of effective links and synergies between schools and research infrastructures in order to spark young people's interest in science and in following scientific careers. The foundation for this project is presented within Work Package 2 in five deliverables D2.1 (The features of inquiry learning: theory, research and practice), D2.2 (Essentials of creativity-enriched IBSE pedagogy), D2.3 (Effective learning environments for inquiry learning and teaching), D2.4 (Professional development of Educators: Considerations and Strategies) and D2.5 (A framework for identifying creative best practices in inquiry-based science education).

This deliverable, **D2.1, The features of inquiry learning: theory, research and practice** identifies the essential features firstly of European creativity in education and, secondly of inquiry

learning in science education. It is made up of a review of relevant literature, reports and relevant outcomes of EU projects. It also reports on a series of workshops with key stakeholders who 'exchanged experiences' to contribute to identifying the essential features. The deliverable culminates in a summary of the necessary features of creativity in education and inquiry learning, drawn from all of these different sources.

Sections 1 and 2 introduce the project and the initial definition of creativity in science education with which the project began. They also provide details of the literature review and workshop methodology

Section 3 encompasses the main literature review of academic publications, reports and practice within creativity in education and inquiry learning. It provides the historical context of the nature of creativity, and wider understandings of creativity in education per se, emphasizing the important inter-relationship of creative teaching and teaching for creativity. It then focuses down on what is known about arts partnership and arts/science integration and their pedagogies, before honing in further on creative teaching, teaching for creativity and inquiry learning within science education. This last section considers pedagogies, with a focus on IBSE and the use of technologies.

Section 4 focuses in on the learning outcomes relevant to CREATIONs, from the CREAT-IT project. This details the underpinning theoretical concepts for both projects of Possibility Thinking, the '4 Ps', Wise Humanising Creativity and Living Dialogic Space, alongside the CREAT-IT pedagogical principles. Here these are newly applied to the CREATIONs aim of demonstrating innovative approaches involving Scientific Research through creative arts-based ways to spark young people's interest in science and in following scientific careers.

Section 5 details the findings from the pan-European workshops which aimed to discover: what creativity in science education means for the participants; what initiatives they were aware of that engage students via different means including the arts and culture; and what pedagogies the participants thought were key to using this approach. The workshops refined the creativity in science education definition to the following: *"Purposive and imaginative activity generating outcomes that are original and valuable in relation to the learner. This occurs through critical*

reasoning using the available evidence to generate ideas, explanations and strategies as an individual or community, whilst acknowledging the role of risk and emotions in interdisciplinary contexts". Across the 8 workshops details of nearly 60 initiatives in creative/inquiry-based science education were gleaned; and the CREAT-IT pedagogic principles were debated and reinforced.

Section 6, finally, synthesizes all of the above. It emphasizes the importance of creative science teaching and teaching for creativity within inquiry science learning as fundamentally relational and grounded in professional wisdom. It offers the eight CREATIONs features as follows: Dialogue; Interdisciplinarity; Individual, Collaborative and Communal activities for change; Balance and Navigation; Empowerment and Agency; Risk, Immersion and Play; Possibilities; and Ethics and Trusteeship. This section culminates with an exemplification of the inter-relationship of the CREATIONs features and IBSE pedagogies.

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Acknowledgements

The University of Exeter team is extremely grateful to all CREATIONs colleagues who provided literature for the review within this deliverable, and who carried out and documented workshops

with experts in the field to inform the new CREATIONs features. We would like to thank the participants who attended the workshops for providing the team with insightful comments and examples of current good practice happening in their country.

1. Introduction

This deliverable identifies the essential features of creativity in education and inquiry learning that are relevant to the European context. It is made up of a review of relevant literature, reports and relevant outcomes of EU projects. It also reports on a series of workshops with key stakeholders who 'exchanged experiences' to contribute to identifying the essential features. The deliverable culminates in a summary of the necessary features of creativity in education and inquiry learning, drawn from all of these different sources.

The deliverable takes as its starting point a definition of creativity in science education that has been developed across two EU-funded projects: Creative Little Scientists (http://www.creative-little-scientists.eu/) and CREAT-IT (Craft et al, 2014). The former focused on creativity in science and mathematics education in early years education, and the second focused on creativity in science education in late primary and secondary education. Across those two projects the following definition of creativity in science education was refined:

"Purposive and imaginative activity generating outcomes that are original and valuable in relation to the learner. This occurs via generating ideas and strategies as an individual or community, reasoning critically between these and producing plausible explanations and strategies consistent with the available evidence".

This definition was included in the stakeholder workshops and developed for the CREATIONs project. The outcome of this process can be seen in section 5 of this deliverable.

From here, the deliverable offers methodological information as to how the literature review and workshops were carried out (section 2); it provides information on creativity in education per se, and on creativity in science education (section 3); it details key learnings from the previous CREAT-IT project (section 4); it details workshop outcomes (section 5); and offers the final synthesis of these (section 6).

2. Methodology

2.1 Literature Review

The literature review has been compiled building on the Literature Review from D2.1 of the CREAT-IT project (Craft, Chappell, Slade, 2014). This CREATIONs deliverable substantially revises and updates (using new 2013-2016 literature) understanding of creativity in education to accommodate the inquiry-based learning emphasis, as well as incorporating current literature to 2016. In this process, the following approach was taken:

- The literature review was divided into sections according to the expertise and experience of the research team at The University of Exeter.
- Citation searches were performed for the literature included in the previous review, and recent research studies and reports were included
- Searches were performed for new literature in relevant search engines and databases, including Google Scholar, ProQuest, BEI, ERIC, and the British Library catalogue. Specific relevant journals were also searched, including International Journal of Science Education, Science Education, Journal of Research in Science Teaching, Education 3-13, and the International Journal of Educational Research.
- The types of literature used included books, research papers, conference proceedings, EU project deliverables, and governmental documents.
- Search terms included: creativity, creativity in education, creative pedagogies, creativity and primary/secondary education, creative partnerships, outreach and participation, cross-curricular learning, STEM, STEAM, inquiry, context and science education.
- The date range was limited to publications after 2012 and studies published in the English language from any country were included, although the majority were from Europe, North America and Australia.
- For the generic creativity in education section, around 70 documents were assessed and of these around half were included as appropriate to the final literature review. For the

Creativity in Science Education section, around 80 documents were assessed and of these around two-thirds were included in the final review.

- Studies were assessed for relevance, quality of methodology and design, relevance and the internal and external validity of the studies. Attention was paid to criteria including sample characteristics (such as size, representativeness and selection); data collection processes, instruments and measures, and the appropriateness and rigour of the data analysis.
- A pro forma was also circulated to project partners to bring in literature from each of the relevant countries. Seven pro formas were received from project partners. The references provided by each country (a total number of 41) were included in the relevant sections of the review.

The ensuing literature review is presented in section 3 of this deliverable.

2.2 Workshops

Workshop guidelines were developed at The University of Exeter, with the intention of creating a living dialogic space via creative learning conversations in which all participants are listened to and have a voice (Chappell and Craft, 2011). The workshop guidelines are available in Appendix 1. This approach was used in order to model the kind of facilitation and pedagogy that the CREATIONs project itself is aiming to encourage. A digital recording sheet was provided to facilitate collection and analysis of data. The guidelines were circulated to all project partners, with a covering email explaining that they were to be used as guidance but could be adapted according to the requirements of the specific context. Workshop organisers were asked to seek participants from the following categories as outlined in the original project proposal: science educator, science curricula developer, teacher educator, scientist, practitioner, specialist in cognitive psychology, sociology and/or learning sciences, and were requested to recruit around 15-20 participants for each workshop. A suggested timeline for organization and completion of the workshops was provided. 12 workshops were completed in five partner countries. Data from

the workshop documentation was collated onto an excel spreadsheet, and analysed in relation to the creativity definition, and in terms of appropriateness of the presented principles. In both cases, the emerging themes were generated using a constant comparative method and coded. The outcomes of this process are presented in section 5 of this deliverable.

3. Literature and report review

3.1 Nature of creativity

There has been a great deal of work on the nature of creativity over time, which spans many centuries and multiple disciplinary perspectives (Craft, 2001). This work was summarised very briefly in Deliverable 2.1 of the CREAT-IT project (Craft, Chappell and Slade, 2014). As the CREATIONs project builds on that research project and its theoretical framework, that summary of the historical background of the nature of creativity is used here to provide the context for this review too. Both projects are informed by research in the social sciences, arts, and science. From this point onwards this section 3.1 is quoting from the CREAT-IT deliverable Craft et al (2014). After this point, the deliverable builds on the strong literature review foundations of the CREAT-IT project to develop this CREATIONs project deliverable.

"Whilst there are, and have been over the ages, many approaches to the nature of creativity there is also broad agreement across disciplines that at its most fundamental, inherent to creativity is generating new approaches or questions that facilitate transition from what is known ('what is) to what is new ('what might be'). Manifestations of creativity are outcomes (which may be products but equally may be ideas) that are considered both original and novel and also valuable (or useful) (see for example Boden, 2004; Craft, 2005; Csikszentmihalyi, 1996; Mumford, 2003; and Sternberg & Lubart, 1999). Creativity may also be encompassed in the very framing of new questions, in the making of new ideas, and in reflecting on these.

Creativity is widely recognized as occurring along a continuum, at one end of which is what might be called everyday, or 'little c' creativity, which may be defined as inherently low in originality and low in wider impact. 'Little c' creativity involves having an idea which is novel to the person who has generated it or the small group surrounding them – but which may not be novel more widely. Examples might be: working out a new or alternative way to travel from A to B, planning a novel menu with unusual ingredients, proposing a change intended to improve a school community, or generating a group question for investigation in a science lesson. There are various ways in the literature of referring to such everyday creativity. In the United Kingdom, the personal-level novelty is referred to by psychologist Boden (2004) as

'psychological' creativity, and thus for Boden the idea is 'P-creative'. For social scientist and educator Craft (2001) the term is 'little c' which she relates to life-wide resourcefulness and personal effectiveness. In the United States, meanwhile, psychologists Kaufman and Beghetto (2009) separate what they call 'mini-c' creativity (for them meaning personal meaning-making) from 'little c' or everyday creativity (for them meaning creativity shared with others). Kaufman and Beghetto also introduce the interesting concept of 'pro-c' or professional creativity.

At the other end of the creativity continuum, reflecting high originality and high impact, is 'big c' creativity (such as that possessed by physicist Albert Einstein, or dancer Martha Graham). For Boden this is 'H' creativity in other words historical creativity, which actually generates such novel ideas that a paradigm shift occurs or the world is changed.

This present-day continuum of creativity reflects the perspective that human beings are highly creative and that creativity is generated by them working individually and together. But this perspective was not always the dominant one; in pre-modern perspectives, the source of creativity was seen as what Sawyer (2006: 12) calls a 'superhuman force'. Sternberg (1999) discusses how Plato, for example, from his classical perspective, saw the creator as 'receiving' divine inspiration passively. According to Sternberg, Plato referred to the creator whether artist, scientist, musician, poet, sculptor etc., being 'an empty vessel that a divine being filled with inspiration' (Sternberg, 1999:90). This mystical perspective was, Sternberg points out, a barrier to the exploration of creativity since it was seen as mysteriously 'emerging' from a divine place and being impervious to explanation.

In stark contrast, since the Renaissance this perspective has been turned upside down, as Sawyer discusses (2006): human beings being recognized since this time as highly creative in and of themselves, and as a consequence, the study of creativity grew from this historical point. This is not to forget the work of Comenius stretching back into the seventeenth century (1657) who was one of the first to discuss educational methods and the balance between imitation and creativity. This aside, psychology is perhaps the most developed field of the study of creativity and the next part of this review considers three particularly influential traditions of psychological enquiry into the nature of creativity, that have developed during the 20th century: cognitive, psychometric and humanistic.

The cognitive approach: Wallas (1926) undertook some of the earliest cognitive psychology work with a focus on modelling. He highlighted four vital parts to what he described as the 'Art of Thought': preparation, incubation, illumination and verification. It is documented that Wallas attributed 19th century physicist Hermann von Helmholtz, Freud and the British romantic poet Shelley as inspiration for his model (Espeland, 2004). Since Wallas's work, this creative process of the 'Art of Thought' has been added to by other researchers who, following Rhodes' (1961) seminal work, have identified four dimensions: creative outcomes (or product), characteristics of creative individuals (or person), habits or patterns involved in being creative (process) and finally convincing others that something is creative (persuasion, also sometimes referred to as 'press'). In 2007, Watson added the role of culture and environment (place) and more recently Kozbelt, Beghetto and Runco (2010) recognized that creative ideas are sometimes unexpected and may be dismissed, especially in a classroom – yet may signify potential. Some cognitive studies of creativity drawing on psychology as applied to other related disciplines, explore how creative habits arise, and tensions between automatic reflex behaviour and habitual creativity.

The psychometric approach: Guilford was the first researcher, in the 1950s, to apply measurement, using psychometric tests, to creativity. He was interested in everyday creativity and how individual differences in forms of thinking could be measured from a truly psychological perspective. As Sawyer (2006) reports, such tests were and have been over many years very popular, as they are easy to administer and score, and offer the opportunity to work with large populations. Some of the most widely used tests are the Torrance Tests of Creative thinking (TTCT) (1974). Translated into many languages (Baer and Kaufman, 2006) these tests are for use with adults and children and involve verbal and figural components. Responses to the tests, which essentially foster divergent thinking using uncontextualized test papers (like all psychometric tests), are scored for originality, flexibility, fluency, elaboration, abstractness of titles, and resistance to premature closure. Other tests have been developed more recently by Lubart, Besancon and Barbot (2011), which go beyond the initial focus on divergent thinking in the Torrance Tests. These new tests encompass convergent (or integrative) thinking as well as divergent (or exploratory) thinking and are designed for use with children between the ages of 6 and 14. Scored by trained judges through an online system, a creativity profile is generated for each participant.

Proponents of the psychometric approach argue that such tests can, by measuring creativity, also provide a starting point for enhancing it. On the other hand critics challenge the fact that context is not recognized, and that they adopt a far too narrow definition of creativity which correlates weakly with other creative behaviour indicators. Yet, because of their ease of administration the tests remain popular and, with its promise of 'test outcomes', the psychometric stance is one that retains influence.

Humanistic approaches: Initiated by Maslow (1943) and Rogers (1954), this line of enquiry into creativity foregrounds personal perspectives and is concerned with motivation. In his 'hierarchy of needs', Maslow modelled how creativity can only be enacted once all basic needs are satisfied. Rogers (1954) meanwhile foregrounded the role of unconditional and positive regard in the development of psychological safety for creative behaviour.

3.1.1 Current directions in creativity research

Early twenty-first century research is strongly influenced by these three traditions; the cognitive, the psychometric and the humanistic. But increasingly the emphasis is turning to many disciplines, as Caselli (2009) argues (drawing from literature from psychology, but also neurobiology, cognitive science and neuroeconomics), to the social dimension of bridging the gap between what already exists (i.e. 'what is') to the enactment of imagination (i.e. 'what might be'). This reflects Craft's and others' work on Possibility Thinking through 'what if?' questions and 'as if' behaviours.

Creativity in the 21st century is increasingly recognized by creativity scholars as a social phenomenon with emotional, or perhaps conative dimensions. Key elements are recognized as motivation, interaction and mood. Relevant here is Csikszentmihalyi's (1997) theory of flow. This is the peak psychological state that people experience when engaged in an activity that is appropriately challenging to the individuals skill level, and can be applied to understanding creativity. Thus, resulting in total immersion and focused concentration on a task. He proposes that this can then result in the individual engaging in deep learning as they are experiencing high levels of personal and work satisfaction. Others (for example, Craft, Gardner and Claxton,

2008 and Chappell and Craft, 2011) argue that the 21st century badly needs creativity that attends to its potential impact and indeed that sustaining futures require wise, humanising creativity (Chappell and Craft 2011, Chappell, Craft, Rolfe and Jobbins (2012), Craft, 2013)."

These arguments are picked up further in section 5 below, learning from the CREAT-IT project.

3.2 Creativity in education

3.2.1 Approaches to creativity in education

Craft et al (2014) considered recent literature in creativity in education in relation to the CREAT-IT project objectives. Because of the directly fluid connection between the CREAT-IT and CREATIONs project, this section builds on the core foundations of parts of the CREAT-IT review. These are integrated with new literature, sourced through the CREATIONs reviewing process, since that time and literature which is particularly relevant to the CREATIONs inquiry-based science learning and engagement objectives.

Approaches to creativity in education emerging from European and North American research and practice tend to foreground a belief in the capacity of all children to be creative at an everyday level. Such approaches recognize that novelty may be applicable only to the creator/s (Boden, 2004, Craft, 2000, 2001, 2002, 2005, Kaufman and Beghetto, 2009). Eisner (2004) has developed a powerful perspective on children as creative meaning-makers particularly in and through the arts. The long line of the progressive, child centred education movement stretching back to philosophers such as Dewey, but also Pestalozzi (1821, 1898), Rousseau (1899, 1920), Froebel (Bruce et al, 1995; Froebel, 1826, 2001a, b, c, d; Lilley, 1967), and Isaacs (1930, 1945), amongst others, frames this belief in children's creative capacities in meaning-making and generativity. According to Barbot et al (2015), alternative pedagogies such as Montessori and Freire 'lead to higher creative potential in students compared to those exposed to traditional pedagogy' (Bardot et al, 2015: 376). It is important to note also the culturally situated nature of creativity, as highlighted by Newton and Newton (2014) in their synthesis of research related to creativity around the world which highlights the differing prioritisation of individual and collective

creativity. Lin (2011) also makes make a distinction between product-orientated creativity in the global East and process-oriented creativity in Western conceptions of creativity.

A view of creativity as universal to all children prevalent in educational literature is recognized by Banaji et al (2010a) as a 'democratic' approach, a term used earlier by others including, in England, the influential National Advisory Committee on Creative and Cultural Education (NACCCE, 1999). Banaji et al (ibid), analysing how creativity in education has been applied in practice, identify nine different discourses of creativity in education, which aside from the first (which focuses on extraordinary creativity), foreground capability in all children. The discourses they name as Creative Genius, Democratic and Political Creativity, Ubiquitous Creativity, Creativity as a Social Good, Creativity as Economic Imperative, Play and Creativity, Creativity and Cognition, the Creative Affordances of Technology and The Creative Classroom.

The most recent research shows that creativity in the classroom in the UK is being placed under considerable pressure by the constantly increasing accountability and performativity culture in schools (Cremin & Barnes 2014), as can be seen in the most recent major UK policy document on creativity (Neelands et al, 2015). In this document, creativity is seen as a driver for entrepreneurship and economic growth and the creative industries are valued for the contribution they make to the national economy. Teachers are challenged by external demands to raise standards in achievement, which can place creative teaching under threat in a culture of results (Cremin & Barnes 2014).

Glaveneau et al (2015) highlight that we are living in a culture which aligns creativity to the needs of capitalist societies, and question the impact of this on approaches to creativity in education. Drawing on dialogue between researchers based in Denmark and Colombia, they also draw attention to the situated cultural and political nature of creativity, and the need to 'build a critical cultural approach to creative pedagogy that engages with paradigmatic discourses and notices how they are embodied in everyday practices inside and outside the classroom' (Glaveneau et al, 2015: 361). They argue for the need to move away from what they term the 'He-paradigm' of creativity, the Western concept of the creative genius, towards a 'We-paradigm' which encompasses collaboration and draws on new models of creative pedagogy emerging from the global South, which 'account for and strive to transcend colonialism and oppressive

relations embedded even within seemingly collaborative classroom interactions' (Glaveneau et al, 2015: 365). The authors consider that by drawing on the lessons gained from dialogue between two culturally diverse conceptions of creativity, a more questioning stance towards a genuinely inclusive approach to creativity may be achieved, which asks whose creativity we are celebrating and valuing.

3.2.2 Creative pedagogies in upper primary and early secondary teaching

The key distinction made in creative teaching between a focus on pedagogy ('creative teaching') and a focus on learning ('teaching for creativity') is explored in the following section.

There has been a great deal of research into creative pedagogies in upper primary and early secondary teaching. These are briefly explored in this section in relation to standard classroom practice, which may involve some partnership with colleagues from beyond school but is mainly facilitated by teachers; the next section explores these specific creative pedagogies.

Cremin and Barnes (2014: 467) highlight that 'creative teaching should not be placed in opposition to the teaching of essential knowledge, skills and understanding' stating that it 'involves teaching the subjects in creative contexts that explicitly invite learners to engage imaginatively and that stretch their generative, evaluative and collaborative capacities' (also reinforced by Chappell et al, 2011). Cremin and Barnes also draw attention to the interdisciplinary nature of creativity; it is not limited to distinct subject areas but depends on 'interactions between feeling and thinking across boundaries and ideas' (Cremin and Barnes, 2014: 471). Key elements in creative pedagogy were highlighted by Woods (1995, 2002) drawing on his ethnographic work in primary schools in England. Where teachers taught in a creative way, they engaged children in learning that they felt was relevant to them, over which they had some ownership and control and through which they could be innovative. As shown in a later study by Craft (1998) including secondary teachers as well as those in primary schools, very similar elements were present in their experience of creative teaching, including:

- A commitment to engaging in relationship with their pupils, others with whom they work in nurturing pupils, and nourishing their own emotional, intellectual and spiritual identity as teachers (reflects Woods' *relevance* for pupils)
- Importance of professional judgment (reflects Woods' *ownership* for pupils)
- Critical reflection on their teaching and adaptability of practice as appropriate (reflects Woods' *control* for pupils)
- Willingness to take risks to generate something novel (reflects Woods' *innovation* for pupils)

Kuntz et al (2013), working to develop collaborative creative pedagogical practices in elementary schools in Alabama, USA, identify that much of what teachers consider to be their most creative activities and insights occur within the confines of the classroom walls, and consider that one of the most important methods of developing teacher creativity is to address reluctance to share some of their most innovative and least outcome driven practices. They discovered that by encouraging teachers to communicate and collaborate with their peers, it was possible to reflect upon and develop their pedagogical creativity within the constraints of state and school driven programmes and targets.

3.2.3 Creative teaching and teaching for creativity

The distinction between teaching in a creative way (creative teaching) and teaching for creativity (fostering creativity in students within particular disciplinary areas) was made by Jeffrey and Craft in 2004. This important distinction will frame the CREATIONs project, which seeks both to foster creativity in science and also to engender this in a creative way. A discussion of the distinction between creative teaching and teaching for creativity was made in a landmark national policy report on creativity in 1999 (NACCCE, 1999), but Jeffrey and Craft warn against the dangers of simplistic polarization recognizing that, as the NACCCE Report (ibid) acknowledged, 'young people's creative abilities are most likely to be developed in an atmosphere where the teacher's creativity abilities are properly engaged' (ibid, p90). Indeed the

NACCCE Report states the view that 'teaching for creativity involves teaching creatively' (ibid p90). In their article, Jeffrey and Craft highlight that creative teaching involves making the curriculum relevant, offering children control and ownership and ensuring they can innovate, and that at the heart of this is 'passing back control to the learner' (Jeffrey and Craft, 2004: 81). They recognize that this involves possibility thinking (Craft, 2002 and discussed later in this review) at the heart of which is listening to children's questions, encouraging them to investigate and to identify problems to solve. They also recognize the role of co-participative approaches in which teachers and learners are engaged dynamically and collaboratively, and where children's perspectives help to guide the learning – what Jeffrey and Craft (2004) call a learner inclusive stance.

Lin (2011) working in Taiwan with older primary pupils through drama, uses the term 'creative pedagogy' to encompass both creative teaching and teaching for creativity, and Kuntz et al (2013), working in Alabama, USA with elementary school teachers, consider that 'creative pedagogy' 'enables a teacher's sense of agency by addressing his/her own pedagogical goals, as well as those dictated by state and local standards' (Kuntz et al, 2013: 43). Whilst the distinction between creative teaching (teaching in an imaginative way) and teaching for creativity (fostering children's creativity in particular ways) is a very important one for CREATIONs, perhaps even more important is how they come together dynamically in a learner inclusive perspective blending the learner's voice with disciplinary understanding relevant to the context. Through confidence in their ability to recognise and employ their own creativity, teachers are empowered to offer children 'spaces for emotional and intellectual growth' (Cremin & Barnes, 2014: 471).

A study in primary level performing arts (Chappell, 2007) considered creative pedagogies as a balancing act working towards blending children's own voice and their disciplinary knowledge and understanding (in this study in the form of arts-based compositional knowledge). The findings showed that creative pedagogies involved using tasks and strategies from three core pedagogical spectra. The three dimensions were intricately intertwined within the teachers' practice and were:

1. Prioritisation of *creative source—'inside out' or 'outside in'* (whether the task source was prioritised in the children's ideas and impulses or the teachers'

ideas/dance knowledge). This meant responsive shifting between inside or outside as sources of theme, movement and opinion, in order that they authentically gave voice to ideas which were meaningful to them in dance

2. Degrees of *proximity and intervention* (supporting and challenging creative ideas using *distanced reactivity* or *close-up proactivity*). Proximity was indicative of the amount of freedom the teachers allowed the children per se for creativity
3. *Spectrum of task structures—purposeful play* to *tight apprenticeship* (shifting between employing play-based task structures characterised by '*risk-taking', 'acceptance of failure', 'fun, silliness and mess'* and apprenticeship structures characterised by *tight parameters, 'safety' and 'structured stages', progression contingent on 'step-by-step success'* and *'hard work'*).

Appropriate to the situation, across the above this meant:

- Sharing responsibility for the creative idea gradually, immediately or passing it backwards and forwards to varying degrees
- Allowing differing amounts of keeping control and freedom from having control, which allowed for
- Providing differing amounts of space within tasks for 'bursts of creativity' or more sustained creative explorations

The study's articulation of this complexity suggests both that it cannot be assumed that creativity automatically occurs when teaching the performing arts, and that there is a subtlety, and wisdom of experience within teachers which contributes to teaching for creativity of which is vitally important to remain aware.

A further ethnographic study by Craft et al (2013) at two primary schools in England discovered that the schools shared three key characteristic features of creative pedagogies:

1. Co-construction: Rojas-Drummond et al (2006) characterise co-construction as

the 'joint efforts of coordination, negotiation and collaboration in various group work activities' (Rojas-Drummond et al, 2006: 92). The researchers noted that the 'important feature of co-construction in each school was emphasis on real life contexts and relevance' (Craft et al, 2013: 11). Shared reflections were valued and inclusive teaching approaches involving both pupil and teacher were embraced. The study reports how researchers recorded teachers co-constructing the curriculum, while at one school the children had been designing their own pathways for many years.

2. Children's control / agency / ownership. Each school provided 'a trusting, agentive environment' that encouraged 'children's decision making, offering them ownership and control over their learning' (Craft et al, 2013: 12). At one school the children's control, agency and ownership were fostered through creative and reflective practice that supported and enabled their ideas. The teachers felt empowered as they had the freedom to plan according to children's interestsand the children became more engaged as they had agency over the curriculum. The children were also involved in developing spaces that documented their work, thus they were motivated, and more confident as their self-expression was allowed.
3. High expectations in skills of creative engagement. The teachers observed during the ethnographic study held 'high expectations in relation to the development of children's skills in learning' (Craft et al, 2013: 14). Staff were were supported through professional development opportunities and ongoing shared reflection and learning.

Of relevance to CREATIONs is that in both schools, pedagogy for everyday creativity was integrated with the arts and that the value of the arts was harnessed as 'inherently motivational' (Craft et al, 2013: 16).

In a systematic literature review of creative learning environments in education ranging from early years to higher education, Davies et al (2013) identified the following key attributes of learning conditions that promote creative skills development:

- *The physical environment:* evidence from a number of studies suggested that spaces should be usable flexibly and promote openness and spaciousness
- *Availability of resources/materials:* access to a wide range of appropriate material, technical, learning and ICT materials (becoming more specialised as pupils get older) can stimulate creativity
- *Use of the outdoor environment:* evidence from some studies suggested that taking pupils outside the classroom can help to foster creativity
- *The pedagogical environment:* strong evidence from a range of studies suggested that increased control over learning and capacity for risk-taking, combined with the right balance between structure and freedom, enhanced creativity
- *The role of play:* bringing more 'playful' approaches into the classroom enhances creativity at all ages
- *The use of time:* evidence suggests that creativity is best served through flexible use of time
- *Relationships between teachers and learners*: pedagogic relationships that are flexible, spontaneous, dialogic, and collaborative enable the development of creativity
- *Use of other environments beyond the school*: there is reasonable evidence to suggest that work in environments such as museums and galleries can enhance creative skills, and that engagement with outside agencies including community organisations can contribute significantly to a creative learning environment, as such organisations 'can embody innovative practice' (Davies et al, 2013: 87)

The review's authors also highlighted the potential impact on pupil attainment of creative learning environments, and stated the need to clearly 'distinguish between the roles of 'critical

events' (projects, themed weeks, work with outside agencies) and ongoing and good classroom practice in the establishment of creative environments' (Davies et al, 2013: 89), coming down firmly on the side of creative classroom environments as part of everyday pedagogy, process rather than product driven and centred upon creative skills development rather than outcomes.

3.2.4 Teaching creatively and teaching for creativity

In teaching creatively and teaching for creativity (particularly the latter) there are assumptions about the active involvement of learners and their own meaning-making, which drive pedagogy and shift the relationship between learner and teacher into a particular kind of dynamic.

McWilliam (2008) describes a transition over the last two decades of education in many parts of the world from teachers behaving as 'sage on the stage' (expert, passing on knowledge and expertise in a one-way process from teacher to learner), to 'guide on the side' (supporting learners by close engagement alongside them) to 'meddler in the middle' (engaging in the dynamic of learning with learners); more of an improvisational approach (such as that documented by Sawyer, 2007, 2011, 2012).

The role of guide has been particularly prevalent since the 1980s, in which teachers attend closely to learners and seek to value their creative potential by close observation of their engagement in activities, stepping forward to support them as appropriate. From their qualitative work in English primary schools, Cremin et al (2006) describe pedagogical strategies of teachers who guide children engaged in creative endeavours as:

- Actively standing back
- Offering time and space
- Valuing pupil agency

Building on Woods' (1995, 2002) work, Jeffrey's (2006) Creative Learning and Student Perspectives (CLASP) project, was a two-year European Commission funded report that involved nine countries including: Austria, Denmark, England, Ireland, Poland, Portugal, Scotland, Spain

and Sweden over 22 months (2003-2005). The report explored creative teaching and learning in primary and secondary contexts across Europe and identified the following pedagogical strategies as vital to what might be understood as 'guide on the side' approaches to fostering creativity in children's learning in a range of domains of knowledge:

- The establishment of real and critical events and strategic external co-operations. Critical events frequently developed over time and revealed each of Woods' processes of relevance, ownership, control and innovation in actionThey were often encapsulated within a special period of time – sometimes integrated with the entire curriculum and sometimes operated separately, though there was usually someengagement with particular domains of knowledge. Critical events usually also involved collaboration with external partners (artists, visits, project specialists, workshop providers). Each of the sites researched drew strength from its critical events and strategic partnerships to resist the the pressures of assessment across Europe within much narrower elements of the curriculum (Ball, 2000), Two particular aspects of critical events were highlighted by the research team.
- Creative Use of Space. Critical events frequently involved changing the nature of learning spaces, often moving the whole teaching group into unusual actual and virtual learning spaces. The re-design and re-use of space though was not always, the project reported, successful. Not all students found it easy to engage in new learning contexts and the research team interpreted this in relation to the 'cultural capital' which children brought to the learning context (Bourdieu and Passeron, 1977).
- Creative Use of Time. Time was often stretched, lessons lasted longer and continued as long as interest was sustained giving time for depth of engagement,
- Modelling Creativity, Jeffrey (2006) reported that teachers across Europe modelled creativity They took a real interest in children's ideas, put significant time into discussion and critique, worked alongside and in collaboration with partners and acted spontaneously, engaging in learning and demonstrating pleasure at innovations generated (something previously noted by Jeffrey and Woods, 1997 and Woods and

Jeffrey,2006). Spontaneous activity also included making changes in plans to classroom activity.

These classroom strategies documented by Jeffrey (2006) for fostering creativity in late primary and early secondary education are also found in creative partnership between artists and teachers that focus on the fostering of creativity in specific curriculum areas.

All of these well developed and well documented strategies involved teachers guiding, and operating alongside, children. However, McWilliam (2008) discusses an evolving edge of creative practice, which she names 'meddling in the middle'. For McWilliam, teachers who meddle in the middle:

- Value uncertainty
- Encourage risk-taking
- Design, assemble, edit alongside pupils
- Actively co-evaluate

Such improvisational-oriented practices were documented by Chappell et al (2011) in a study of creativity in dance among lower secondary pupils developed through creative partnership between dance practitioners, teachers and pupils. Craft (2011) discusses the ways in which these partnerships generated meddling in the middle activity.

Craft (2011) considers how the enquiry can develop McWilliam's 'meddling in the middle' to open up 'possibility spaces'. The Dance Partners for Creativity project funded by the Arts and Humanities Research Council, found examples of meddling in the middle that were unique and transformative. Comments from the partners suggest that 'meddling' appeared to permeate the classroom practice and the student's creativity and create spaces of possibility to stretch and challenge the partners and students.

The theoretical and research approaches to creative pedagogy outlined above indicate that through teaching creatively and for creativity, collaborations with 'creative partners', and the

integration of arts methodologies into inter-disciplinary teaching, pupil agency, ownership, motivation and engagement can be heightened, alongside the development of higher-order thinking and problem-solving skills. Real-life issues and contexts for learning are utilized to increase relevance to the learner and both teachers and learners are enabled to develop collaborative learning relationships based on trust, communication and the creative use of space and time within and outside formal learning environments.

3.2.5 The arts, partnership approaches and arts science integration

Role of the arts

The way in which the arts has contributed to creativity in education per se has been written about at length by eminent arts education philosophers such as Abbs (1996, 2003) and Eisner (e.g. 2004). In 1996 Abbs, based in England, wrote about the shifting paradigms in education and identified a new paradigm in British arts education. He suggested that, from the early 19th century until the 1980s, the arts were taught under the titles of Progressivism and Modernism, but this shifted in the 1980's to a new emerging paradigm 'based on a different set of premises, practices, and expectations' (Abbs, 1996: 63). The old paradigm considered the teacher in the role that releases the child's 'innate creativity through acts of self expressions and self discovery' (Abbs, 1996: 66).

However, Abbs argued that the contemporary education of that time, ignored aesthetic education in response to the growing economic imperative focus of the education system i.e. creativity was being ignored as education focused on the quantitative measuring of results (see: Ball, 2000, 2003, Sternberg, 2003). He outlined the paradigm shift by identifying the following three elements:

- The intrinsic value of art
- The place of tradition reconceived as the aesthetic field
- The idea of the arts as a generic community

Abbs (1996) suggested that in this new paradigm the arts were not seen predominantly as an act of self-expression. The new paradigm considered the arts to be a 'vehicle of human understanding' (Abbs, 1996: 70). If the child's ability to be aesthetic is considered innate then Abbs (1996) concluded that we could develop this by introducing the child 'into the living tradition of the art form' (Abbs, 1996: 70). He wanted teachers to not just instruct students about Dickens, Shakespeare and Beethoven but introduce them and educate them within the aesthetic field as a whole, rather than the separate fields of Art, Music, Dance and Drama as was prescribed by the British education system at that time. This divide in the aesthetic subjects remains in the UK, and can be seen across the European curriculum documents. What effect would a more holistic approach have? Barnes (2015: 12) proposes that 'creativity is best stimulated in cross-curricular and authentic contexts'; he states that inter-disciplinary learning allows for meaningful, motivational education experiences that integrate the latest technological developments and foster the development of inter-personal relationships.

Craft et al (2011) argue that children will only be able to develop their creative capacity through a 'rounded curriculum, which encompasses both the arts and a specific commitment to creative teaching and learning.' (Craft et al, 2011: 1). They highlight that when students participate in multiple arts education events they will also experience 'increased achievement motivation and engagement, creativity, enhanced school climate and community engagement' (Craft et al, 2011: 3).

They recommend that schools need to improve their learning environment so that children can nurture and develop a deeper understanding of education in contrast to their perception that children are being taught by rote. The content of the curriculum needs to be engaging so that students are challenged to achieve academic excellence, and finally that the community of learning needs to be broadened so that the boundaries of learning are extended beyond what is considered the traditional classroom.

Eisner (2004) also argues for a strong shift in the US education system. He describes six artistically founded qualitative forms of thinking.

- The ability to compose purposeful qualitative relationships

- The formulation of aims
- That form and content are inextricable
- That not everything knowable can be articulated in propositional form
- There is a relationship between thinking and the material
- Motives for engagement

By proposing the question 'what minds do we want our children to have?', Eisner considers that a child is not born with his or her mind, but that it is shaped by experience and culture. He cites that the arts promote a different kind of thinking and that education can learn from this, but to achieve this would require schools, staff and students to change their perception of learning. Eisner suggests that the arts play a motivational role and can encourage students and teachers to be 'flexibly purposive' to encourage children to learn via their curiosity and to prepare teachers to allow for the unexpected.

Partnership approaches

From the turn of the 21st century, following the NACCCE Report (1999) in the UK there was an increased emphasis in English education on creative partnership as a means to encourage the kinds of creativity and creative learning discussed above. Creative Partnerships is a programme that ran from 2002 to 2011 in the UK, for schools and young people, managed by the Arts Council England and funded by the Department for Culture, Media and Sport. The aim of the programme was to nurture the creativity of young people alongside developing the skills of the teachers by working with creative practitioners. Often but not always the partnerships were established between professional artists and arts educators coming in from outside the school to work with teachers from a variety of disciplines.

Various models of practice were developed as framing devices for theorising and practicing creative partnership and the intended ensuing creative outcomes. These models include that proposed by Griffiths and Woolf (2004) who situated partnership engagement as a version of

'apprenticeship learning'. A comprehensive investigation and report by Animarts into the 'art of the animateur' (Animarts et al, 2003) concluded that effective and sustainable 'creative partnership' projects developed teamwork, respect and mutual support between artist and teacher, which was mirrored in pupil attitudes towards their peers and resulted in increased levels of achievement. The report also found that cross-arts projects allowed for fundamental re-thinking and developments in practice, an idea could also perhaps be applied to collaborative arts and science projects. As part of this wave of activity, although creative partnership principally manifested itself as a partnership between the school, the teacher and an external artist, it also, occasionally, involved non-arts partners like scientists.

Many studies have looked at the role of the artist in partnership with the classroom teacher (see; Jeffery, 2005, Jeffery and Ledgard, 2009, Rolfe, 2011). Thomson, Hall, Jones, & Sefton-Green's (2012), recent study investigated the dynamics of the pedagogies within creative partnerships and how they nurture creativity. They frame their Creative Signature Pedagogies (CSP) by adopting the UNESCO framework referred to as the 'four pillars of learning for the 21st Century: learning to know, learning to do, learning to be, learning to live together' (UNESCO, 2008: 8). They challenged the English default pedagogy of lesson structure, based on outcomes and assessment objectives, by suggesting their own pedagogic platform that 'creative signature pedagogies challenge school as a non-place by building sociality and the capacities of young people to become somebody' (Thomson, Hall, Jones, & Sefton-Green, 2012: 16). Other studies have also showed that schools commented that Creative Partnerships provided an opportunity for students to solve problems and that they saw an improvement in pupil behaviour and school performance (e.g. Kendall et al 2008).

Part way through the period of Creative Partnerships delivery the British Market Research Bureau assessed the programme and the wider impact it had upon the schools, teachers and students (Collard, 2006). They found that 70% of head teachers reported that there was an improvement in pupil behaviour. The evidence indicated that by working in partnership with arts organisations, creative professionals and artists across all phases of education schools began to see an improvement in their students' attitudes and abilities.

Galton and Page (2015) have explored the impact on pupil wellbeing of creative initiatives by

conducting a case study of three schools which were involved in extended Creative Partnership programmes; they found that activities adopted under the Creative Partnerships umbrella enhanced both hedonic and eudaimonic aspects of wellbeing, and that the adaptation of a curriculum which promotes pupil choice and opportunities for self-direction and feedback could help to enhance intrinsic motivation, autonomy and self-efficacy.

The National Foundation for Education Research (Sharp, 2007) tracked 13,000 students across the period of delivery and noticed that children who attended a Creative Partnership activity out -performed their classmates, who did not attend, in English, Mathematics and science. Their 2008 report concluded that the same students' improvements in academic attainment were being maintained and on average were scoring 2.5 grades higher than students who did not engage with the Creative Partnerships.

Denmead (2013) synthesised research into the pedagogies of UK artists, musicians and performers working with young people within and beyond Creative Partnerships. Whilst highlighting the danger of using a blanket definition of 'creativity' to refer to all creative arts practitioners and emphasising that creative practices within art forms are different, he identified some common themes in pedagogies:

- Artists establish collaborative relationships with students
- These collaborative relationships have an important emotional dimension, involving artist empathy with student feelings about their work and a supportive environment which enables risk-taking
- There is a significant experiential dimension to the work – for example, choice of real-world locations for artistic performance
- The material dimension is important, including new approaches to use of space

Denmead summarizes his findings as follows – 'artists are attempting to create contextually dependent conditions that are conductive for children and young people to extend possibilities for action and meaning' (Denmead, 2013: 337)

Burnard and Swann (2010) investigated the pupil perspective on creative partnership learning through a study of an artist-led composing project in a UK comprehensive school, Three key themes emerged:

- Learning relations: pupils referred to artists as 'experts' or 'guides', collaborating with them like theirpeers, getting to know them as individual composers rather than just 'pupils', and teaching them to trust their own ideas, building on existing knowledge
- The emotional dimension: working alongside artists was characterised by pupils as deeply personal and allowing space to draw on the peaks and troughs of the emotional dimension of learning– pupils reported increased self-confidence, but also discussed how the artists had helped them to channel negative emotions these into productivity
- Contexts for learning: artists chose sites for learning such as churches and open spaces which were outside school, inspirational and supportive bringing a real-world dimension as pupils composed in and for a space. After the Creative Partnerships initiative was concluded, 'legacy' projects were introduced in the UK by Creativity, Culture and Education (CCE). As part of this, Thomson and Hall (2015) carried out the 'Signature Pedagogies' project, as detailed above.

Fautley et al (2011) describe two secondary schools that re-formulated their curriculum according to principles of creative pedagogy Significant curriculum time was allocated to cross-curricular themes, and drama methodology informed pedagogy based on active learning, encompassing problem-solving. Teachers focused on higher-order thinking skills and quality of oral and written language; teaching and learning relationships were collaborative and trusting.

Teachers reported significant changes to their pedagogical approaches, citing the use of real-life issues that were explored from a range of curricular perspectives, allowing students to act as researchers instead of 'second-guessing ready-made answers' (Fautley et al, 2011; 41), use of dialogic learning leading to increased student participation, confidence in oral presentations and improved active listening, better teacher/class relationships developed from student ownership over learning. Staff reported growing professional competence and personal satisfaction derived

from rediscovered creativity and confidence in their ability to foster 'engaged learning' (Fautley et al, 2011; 41). Students became more confident learners, with a broader perspective on serious issues and ability to access new knowledge and form new concepts, with the necessary technical skills embedded in the process.

Hui et al (2015) report a project in Hong Kong to bring creative drama learning strategies into early years, primary and secondary schools, where teachers received training in drama pedagogy, notable for its encompassing of possibility and 'as-if' thinking, and with the support of a drama educator delivered lessons 'enhanced with drama' (Hui et al, 2015: 397). Students were then assessed through a story telling task and evaluated for various aspects of creativity; researchers found that verbal creativity increased significantly amongst those students who had received teaching infused with drama pedagogy compared to the control group.

Chappell (2008) also offers detail of more interdisciplinary, three-way creative partnerships between artists, scientists and educationalists. She emphasizes that in these circumstances the arts bring the capacity to create 'embodied narratives' within and around scientific knowledge which help to foster creativity in both disciplines. Based on a small study of a number of Wellcome Trust funded science/arts/education initiatives, Chappell (2008) argues that some of the most innovative practices involve science and art collaborations structured in mutually influential relationships, and favour strong discipline knowledge and experience within experts from each discipline. These science-art-learning interactions are characterised by learning gains for parties within different disciplines, which result from the symbiosis between the science and art disciplines. Chappell (2008) emphasizes that at the heart of these kinds of partnerships, creativity within disciplines is different because of different fundamental epistemologies, but the processes at play feature many similarities even if they are structured in different ways.

Arts science integration

Mainly outside of Creative Partnerships style initiatives is the study and practice of arts/science integration. Perhaps the most commonly found integration is in theatre; Nicholson (2011) describes the potential of theatre in science learning, charting a move away from theatre as

promoting public understanding of science to stimulating public engagement and debate surrounding the issues brought about by the rapid rate of scientific and technological change in recent years. She believes that 'theatre is particularly well placed to contribute to public engagement programmes in science [due to] its capacity to generate informed discussion by representing and questioning the social implications of scientific knowledge' (Nicholson, 2011: 177). Nicholson (2011) also states that collaborations between artists and scientists can challenge perceptions, going back to the Enlightenment era, that the arts are intuitive, emotional and empathetic whereas the sciences are founded on abstract reason and logic: 'it is a way of working that recognizes that science, as well as the arts, is inspired by emotion and passion, shaped by intuition, and finds expression in narrative and aesthetic forms' (Nicholson, 2011: 195).

Several studies have explored the use of drama and theatre in creative and science education. In an overview of 10 settings where theatre has been used in education aiming to explore the contribution of performative methods to the learning process, Heras & Tàbara (2014) reached the following conclusions: 1: more engagement when using performing arts in the communication process, 2: the capacity to foster new capabilities, increase imagination, humour and empathy, 3: connecting academic work with communities. Peleg & Baram-Tsabari (2011), working with primary aged children in Israel to investigate the affective and cognitive learning outcomes of watching an educational science play on the topic of matter, found that pupils were able to acquire content knowledge from the play. Watching the play did not change viewers' attitudes towards science or scientists, but it did, however, change their views regarding what school science can be. The students also enjoyed the experience of watching and learning from the play, commenting particularly on the use of humour.

Teachers were also found to use these pedagogies more in their teaching following the training. Working with 34 trainee art and science secondary education teachers in the USA over three consecutive years, Medina-Jerez et al (2012) found that working together on an integrated activity over four sessions significantly influenced teachers' perspectives on collaborative practices.

Ben-Horin (2015) provides an example of arts integration in the sciences in the field of music. In a narrative report of the process of researching and creating a 'neuro-science' opera that sought to explore how the arts might impact the scientific research process of cutting-edge scientific issues, found that a more systematic way for applying the meeting points between professional science and art needs to be explored.

Van Der Veen (2012), working with first year physics undergraduate students in California, researched the use of drawing as a means of assessment for an inter-disciplinary course on the theme of symmetry; her findings suggest that 'drawings and written commentaries can provide insights into students' preferred learning modalities, promote understanding of abstract concepts through visualization, and reveal students' preexisting attitudes toward science' (Van Der Veen, 2012: 1). Although conducted with university level students, this research suggests that the use of visual arts could provide useful insights into learners' understandings of abstract concepts in the sciences.

These examples show that integration of the Arts and Sciences can be generative and engaging for students and teachers. They point to the way in which interdisciplinary teaching can generate discussion and aid access to abstract ideas through engaging contexts, and also point to the way in which the Arts can make explicit for students the human nature of science. Arts/Science pedagogies also offer interesting ways to reveal students' thinking, but it is clearly noted that skilled teaching and therefore teacher education and professional development is important for such integration to be effective. Whilst these examples are by no means exhaustive, they are not intended to be. They are included here to demonstrate the kinds of practices that might ensue from the philosophical treatises put forward by the likes of Abbs and Eisner, and which aim to encourage creativity within different aspects of science education via the arts.

Section 3.2 forefronts the fact that approaches to creativity in education emerging from Europe and North America foreground a belief in the capacity of all children to be creative at an everyday level. However, the review highlights that achieving this is being placed under considerable pressure by increasingly performative education cultures, and the influence of capitalist economic strategies which increasingly pervade education.

This is key to understanding the climate within which the CREATIONs project is occurring. This section goes on to consider the importance of acknowleding the relationship between 'creative teaching', 'teaching for creativity' and 'teaching creatively' in both primary and secondary settings, emphasising the necessity of balance between the two activities in order to encourage creativity for both teachers and learners. In some studies this balance becomes an integration into 'creative co-construction' between teacher and learners (also termed 'meddling in the middle'). The review also includes studies which emphasise the pedagogic environment as part of this balance or co-construction.

The CREATIONs features detailed later in this document incorporate this notion of the importance of the relationship between teacher and learners. Section 3.2 concludes by considering the arts, partnership approaches and arts science integration. It details the historical role of the arts within creativity in educaiton debates, alongside more recent developments of educational partnership initiatives, particularly in the UK which have utilised external arts providers to encourage creativity across the curriculum.

It is these kinds of initiatives which provide a practical and theoretical foundation for CREATIONs. Finally this part of the review details some examples of the many practices of arts/science integration which can lead to better student engagement and generativity. The next section of the review hones in specifically on creative teaching and teaching for creativity in *science* education.

3.3 Creative teaching and teaching for creativity in science education

Having considered the wider picture of creativity in education, honing down to creativity via the arts, and through arts/science integration, we now focus in to consider literature on creativity within science education. The preceding sections have highlighted some key aspects in creativity in education, including the importance of play, creative meaning-making, dialogue and relationships, the generation of outcomes original to the learner, personal relevance and

engagement, environment, time, agency, empowerment, risk-taking and different ways of knowing and using knowledge.

These aspects can be clearly linked to some strong lines of research in the field of Science education, although they may not be explicitly framed as such. These include work on the Nature of Science, where the importance of creativity in the discipline of science is clear (see Lederman 2007), Constructivist science education, focusing on student meaning-making, modeling, and generation of their own conceptual frameworks (see Taber 2009), and Argumentation in Science, focusing on the importance of a particular kind of evidence-based dialogue in the process of generating scientific knowledge and understanding (see Erduran & Jimenez-Aleixandre 2007). It is beyond the scope of this review to explore the nuanced links between creativity and the above lines of research in full. In the following, we therefore explore recent directions in the science education literature linked to creativity, and consider these in light of the facets of creativity already described.

Studies that focus on teaching for creativity in Science fall into similar categories as those relating to creativity more broadly, taking a cognitive, psychometric or humanist view of creativity and studying this in the context of science learning. Thus, some studies attempt to measure the impact of pedagogical interventions designed to stimulate creativity through the use of tests of students' creativity (Siew, Chong and Chin, 2014). Others focus on teacher perspectives and analysis of naturalistic lesson observations to identify creative processes taking place in the science classroom. In the analysis undertaken here, we explore the findings of the relatively limited number of studies into creativity in science learning using the facets of creativity identified in the earlier part of this review. We also analyse other research projects that, whilst not specifically focused on creativity, nevertheless mention creativity as an important process or outcome. Many of these are drawn from projects which aim to develop and synthesise good practices in Inquiry-Based Science Education (IBSE). Synthesising this literature enables us to offer some suggestions for pedagogies that support creative science teaching and teaching for creativity in science. Finally, we consider the impact of assessment of inquiry and creativity within science learning and the constraints and tensions that may arise for teachers in

balancing 'curriculum coverage' and the teaching of specific scientific knowledge with the more open-ended pedagogies suggested.

3.3.1 Creativity in Science Education: Purposes and Perception

Creativity is a key characteristic of scientific knowledge (Lederman, 2007), defined by Meyer and Lederman as 'resulting in a product that is novel, and extends and amends our understanding of the natural world' (Meyer and Lederman, 2013: 400). They delineate creativity (defined by the product) and creative thinking (the process) in science, and argue that both are important in science education. Following the arguments made by Craft (2001), a definition of scientific creativity (incorporating both creativity and creative thinking) could be refined for 'little c' scientific creativity as *activity resulting in a product that is novel* ***to the learner****, amending and extending* ***their*** *understanding of the natural world*. By clearly delineating scientific creativity as relating to science disciplinary aims and knowledge, Meyer and Lederman (2013) acknowledge the role of both broader disciplinary knowledge and students' own science knowledge in teaching and learning for creativity in science.

The necessity of creative teaching and learning for creativity is part of a wider debate about the purposes of science education. As has been discussed by numerous scholars such as Schwartz (2007), science education strives for, or should strive for, conceptual understanding, excellence in the related skills, awareness of practical, social and ethical applications and issues, and some information about the archival roots of science and its place in the broader intellectual tradition. It should contribute to generation of people who are capable of doing things differently rather than simply repeating what has already been done. These ideas suggest that the development of creativity should be an important goal of science education (Hadjigeorgiou et al., 2012). In terms of political aims, the literature suggests that there are multiple purposes to science education related to culture, employability, utility, informed citizenship, a better way of thinking about the world, understanding the popular media, the aesthetic appeal of science, sympathy to science and the importance of technology (DeBoer, 2000). In common with the economic imperative argument for creativity education described in section 2, the need to educate scientists of the future is regularly cited to support arguments regarding an increased focus on

science education research and practice (Craft et al. 2012, Rocard et al, 2007, Gago et. al, 2004), with the ability to innovate seen as a crucial part. Although educational policy makers, researchers and practitioners are often unequivocal about the importance of research and practice in science education, they appear to have varied opinions regarding *how* they should be done effectively, not least in relation to the relevance of creativity and inquiry science.

Despite this recognized need for a scientifically educated population and future scientists, a low level of interest in science subjects by students has been established in the literature (Osborne and Dillon, 2008, Sjøberg and Schreiner, 2010) though this is largely the case in developed rather than developing countries (Wegerif, Postlethwaite, Skinner, Mansour, Morgan and Hetherington, 2013). This lack of interest has been found to stem from multiple possible causes. Bennett and Hogarth (2005) identified the perceived intrinsic difficulty of the subject, the absence of well-qualified teachers, negative attitudes of society towards science and scientists (such as that science is dangerous and it creates problems), the relatively expensive structure of science teaching and science practical applications, and gender issues as the main reasons.

In addition to these, the dogmatic structure of science as perceived by pupils is also considered as one of the fundamental reasons behind students' low level of interest in science subjects. More recently, longitudinal research into 8-14 year old students' aspirations to study science has revealed a broad range of sociocultural reasons for such choices, including gender, race and class, which has been conceptualized using the concept of 'science capital' to explain why large numbers of students see science as 'not for me' (Archer et al, 2013). Interestingly, a clear distinction is noted between 'doing science' and 'being a scientist' (Archer, DeWitt, Osborne, Dillon, Willis and Wong, 2010), indicating that identity and personal involvement are important. Similar findings elsewhere which showed that some students think that in science "there's no room to put anything of you into it" and "everything else is more creative, even history" (Osborne and Collins, 2001: 14) highlights the importance of relevance, identity and creativity in engaging students in science, and resonates with Woods' (1995) elements of creative pedagogy. This clearly has implications for creative science pedagogy in contrast with some more transmissive approaches to teaching science, which directly act to cultivate perceptions of science as a non-creative endeavour.

Educators using those teaching approaches often focus on covering the expectations of the curriculum, which often involves well-structured problems, recipe-style-learning laboratory work, and tightly-timed learning activities for a necessary piece of knowledge (Lee et al., 2007, Niaz, 2008, Reeves et al., 2007).

In challenging this highly structured pedagogy, both practitioners and researchers in the science education domain attempt to incorporate new approaches to teaching and learning, aiming to broaden perceptions of science and increase student interest (Craft et al., 2008, Cukurova and Bennett, 2014, Park Rogers and Abell, 2008). This need not require a complete removal of structure, but a balancing of structured tasks and teacher intervention with student directed agentic activity, enabling 'bursts of creativity' or more sustained periods of creative work along parallel lines to those described by Chappell (2007) in the context of creative arts pedagogy.

Creative science pedagogy (both teaching creatively and teaching for creativity in science) could therefore be expected to increase interest in and longer term engagement with science for a wide range of pupils by addressing issues of relevance and agency. Given that creativity, as has been discussed earlier in this document, is a multi-faceted concept, it has been argued that this requires skills-based approaches to creative science education and training that include contextualised, inquiry-based pedagogies (Schmidt, 2011). These teaching and learning strategies in science are often open-ended, student-oriented, exploratory and group-based. Some pedagogical approaches in the literature that demonstrate these features and thus have potential for creative teaching and teaching for creativity include:

- 'Voice through Choice' in linking their study of science to students' diverse interests by offering a choice of contexts and inquiries through with to learn (Wegerif, 2011)
- Student generation of questions and development of methods to test those questions and engage in meaning-making using Inquiry-Based Science Education (Bogner et al. 2013)
- Engaging students in developing their critical and creative thinking through the use of dialogue and argumentation in science (Yang, Wegerif and Pifarre, 2013)

- Connection of more abstract scientific concepts with real-life applications to increase students' personal understanding of the relevance of science and tap into their own questions (Jenkins and Insenga, 2013)
- Connecting students with the work of professional scientists to model and develop scientific creativity as a key part of the nature of science, empowering students through their own analysis of real laboratory data (Kourkoumelis and Vourakis, 2014)
- 'Playing' and experimenting with scientific concepts and ideas through the use of digital games (Smyrnaiou, Moustaki and Kynigos, 2012)
- Interdisciplinary learning across Arts and Science disciplines, including reference to embodied learning (Chappell et al, in review)

Of course, many of these ideas connect and can be used together to promote students' learning in science, both in terms of content and creativity. Whilst it can be argued that such pedagogies offer a learning environment that is more likely to stimulate creativity by embodying the creative principles of projects like CREAT-IT (e.g. living dialogic spaces and the opportunity for genuine experiment or 'play', see p. 76 of this document), there is as yet limited research evidence that such contextualised, inquiry-based pedagogies do indeed stimulate creativity within science teaching and learning, or through what process.

The current research therefore seeks to contribute to knowledge of the relationship between contextualised, inquiry-based pedagogies and creativity in science learning by developing and exploring pedagogical approaches from across this range within the CREATIONs project as CREATIONs demonstrators. For reasons of space, the remainder of this section will focus on synthesizing the current literature on IBSE as space for creative science pedagogy, and on recent innovative use of technology to support creative science teaching and learning.

3.3.2 Inquiry-Based Science Education (IBSE) as a space for Creative Science Pedagogy

Inquiry-Based Science Education (IBSE) is a pedagogical approach that is designed to offer student opportunity to develop their knowledge and understanding of both scientific content and processes through engaging in investigative, experimental and problem-solving activities. The concept of inquiry has been part of the science education for many years, rapidly gaining popularity during the early 1960s. DeBoer (1991) argues that inquiry has been the most important purpose of science education since the 1960s, although its implementation remains contested and patchy across international contexts over time as a result of changing policy and curriculum requirements.

Despite the recognition of it's importance for science education, IBSE is not very well defined in the literature and the critical need for an agreement upon its definition has been emphasised recently (Capps and Crawford, 2013). The lack of a clear and accepted definition of IBSE leads to confusion in both research and practice (Blanchard et al., 2009). However, there do appear to be some essential features of IBSE (NRC, 2000: 25 as referred in Minner et al., 2010) including:

1. Learners are engaged by scientifically oriented questions.
2. Learners give priority to evidence, which allows them to develop and evaluate explanations that address scientifically oriented questions.
3. Learners formulate explanations from evidence to address scientifically oriented questions.
4. Learners evaluate their explanations in light of alternative explanations, particularly those reflecting sicentific understanding
5. Learners communicate and justify their proposed explanations.

In addition to these, Schroeder et al. (2007) define IBSE as 'student-centered instruction that is less step-by-step and teacher-directed than traditional instruction; [in which] students answer

scientific research questions by analyzing data (e.g., using guided or facilitated inquiry activities, laboratory inquiries)' (Schroeder et al, 2007: 1446). As can be seen from this definition and the essential features of the IBSE identified, students' investigation with curiosity and questions is at the core of IBSE. Rocard et al. (2007) argue that this makes creativity inherently part of IBSE[1].

Teaching strategies that come under the umbrella term IBSE are wide-ranging, and it is not the case the IBSE is synonymous with unguided 'discovery' learning, although the level of guidance offered to students engaging in IBSE activities may vary. In his discussion of investigative work, Wellington (1994) argued that such activity may fall across three dimensions: Open (many possible answers) to Closed (one right answer), Pupil-led (pupils ask questions with no restrictions) to Teacher-led (teachers pose questions or problems for investigation), and unstructured (no guidance given or constraints applied) to structured (guidance given at all stages). The extent to which IBSE could be unguided, with student choice of question, investigative design and analytical approach, has led to one line of criticism of IBL (Inquiry based learning, including but extending beyond the field of science education) as a teaching approach: namely that if learning is equated with changes in long-term memory, unguided inquiry techniques do not lead to learning because searching for novel solutions to problems is an activity with high cognitive load, thus limiting the extent to which information can be transferred to long term memory (Kirschner, Sweller and Clark, 2006). This argument leads to the suggestion that until pupils have sufficient understanding and knowledge of the discipline, they are limited in what they can learn from inquiry-based or problem-solving activities: in effect, this is an argument against pedagogical approaches in science that mirror the process of real science and, therefore, is also an argument against the aim of teaching for scientific creativity in the early stages of science education which has been articulated in a number of studies (see: Washton, 1965; Gangoli, 1995; Kind and Kind, 2007).

In contrast to this, there is a weight of evidence in the literature about the impact of IBSE approaches on students' engagement and interest in science as well as on their disciplinary knowledge and understanding. The results of a number of meta-studies comparing IBSE to other

[1] For a useful summary of good practice in IBSE approaches, see the Fibonacci project resources for implement Inquiry-Based Science Education: http://www.fibonacci-project.eu.

teaching approaches in terms of impact on students' learning gains present positive trends favoring IBSE practices, particularly if the instructors' focus is on students' active thinking and drawing conclusions from data (Minner et al., 2010, Schroeder et al., 2007, Furtak et al., 2012). This suggests that in real classrooms, the impact of pedagogical approaches such as IBSE are complex and go beyond straightforward questions about the impact of the level of scaffolding and guidance on knowledge acquisition. The importance of teacher-student relationships, dialogue and argumentation, interest, engagement, agency and experimentation – and, of course, creativity – are not measure in knowledge gains alone.

Within IBSE approaches, the necessity of some scientific knowledge and understanding is emphasised since the questions on which the inquiry is based need to be scientifically relevant (Bogner et al, 2013). Addressing the issues raised by the application of recent developments in understanding of human cognitive architecture (Kirschner et al, 2006), it has been argued that good practice in IBSE is to offer "scaffolded" learning activities (Hmelo-Silver et al., 2007) in which an optimum amount of guidance should be provided when students can not achieve the goals on their own throughout the learning process. So, given the need for some background knowledge and understanding, and scaffolding by the teacher, how might IBSE pedagogical approaches open a space for creative science pedagogy?

Research studies which investigate creativity in science education in detail are limited in number, inquiry-based pedagogies have been considered as powerful means to help students in enhancing their reasoning activity, their creativity and improving their understanding of scientific concepts both by researchers and teachers (Liu and Lin, 2014). In order to relate inquiry-based science education to concepts in the literature on creativity and education, we take the 'framework for science inquiry' from the Fibonacci Project (Worth, Duque and Saltiel, 2010: 2), reproduced in Figure 1, and consider how the key principles outlined create a space for creative science pedagogy by drawing out some of the different facets of creativity and creative education identified in sections 1 and 2 of this report.

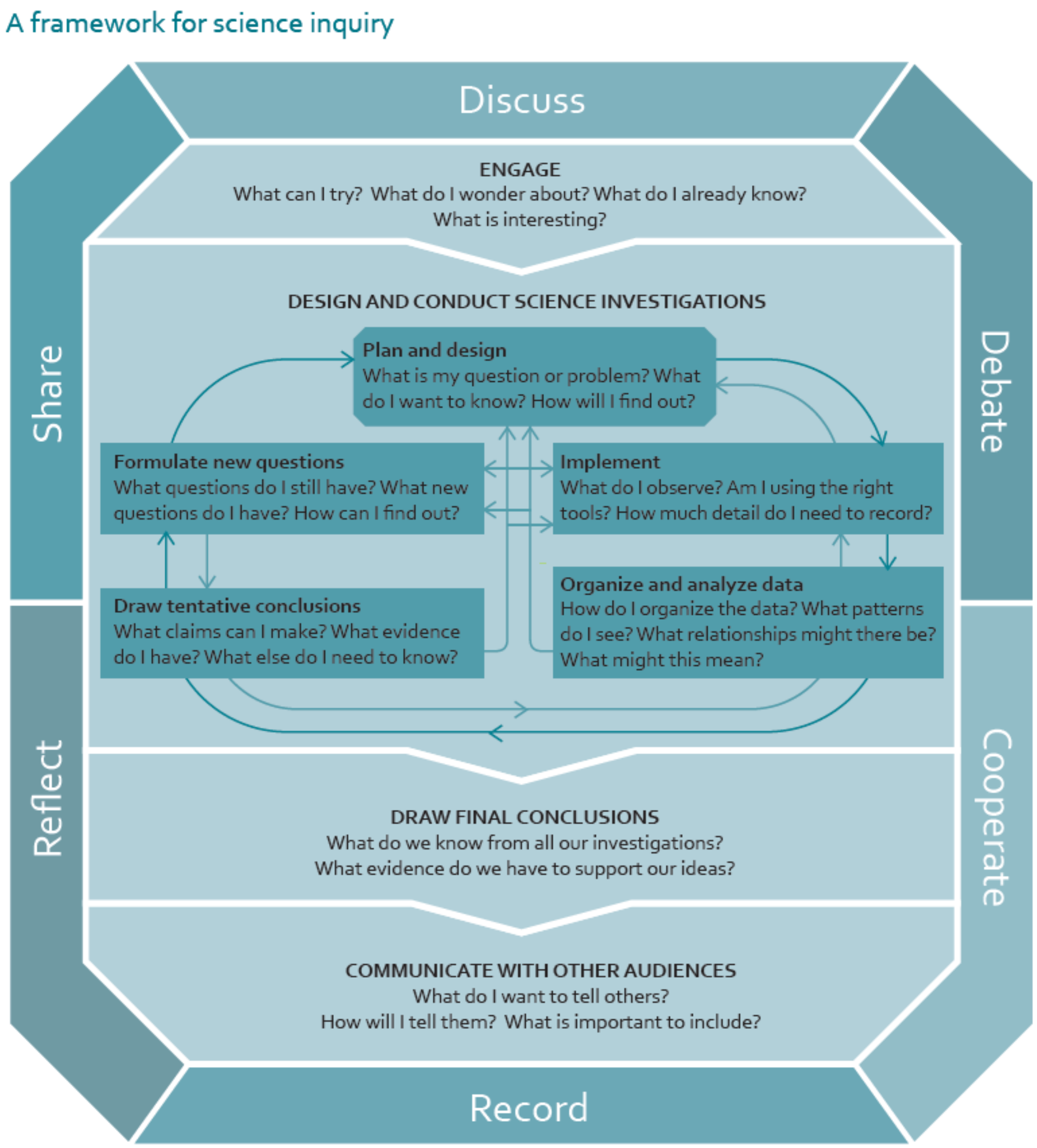

Figure 1: A Framework for Scientific Inquiry, from the Fibonacci Project publication (Worth, Duque and Saltiel, 2010: 2)

Beginning with engaging students in the scientific inquiry draws in the need for discussion of students personal interests with a series of questions: 'What do I know? What do I wonder about? What is interesting? What can I try?' All of these questions could be considered both

individually and collaboratively, and discussed between students and with the teacher in order to reach a consensus about a scientifically oriented question that could be explored and investigated. This is an important element of the process in terms of creativity, harnessing as it does all the synergistic features of creative teaching and learning in science identified by Cremin et al (2015) as relevant in Early Years settings, suggesting that these features may also be relevant for older learners, too. These features: play and exploration, motivation and affect, dialogue and collaboration, problem-solving and agency, questioning and curiosity, reflection and reasoning, and teacher scaffolding and involvement, not only characterise potential ways of engaging students at the outset of an IBSE activity, but also link to later stages of an inquiry, as illustrated in the Fibonacci framework with the concepts 'discuss, share, debate, cooperate, reflect and record' appearing around the edge of the diagram. Much of this work is clearly identified as collaborative, a key aspect to creativity in science that both Schwarz et al. (2015) and Abdu et al. (2015) have argued is developed through IBSE, and can be facilitated within a whole-class context with suitable technologies. We shall return to this point in the next section, discussing the use of technology in creative science pedagogies.

An additional key aspect to creativity identified earlier in this document relates to the notion of 'possibility thinking' and the idea that across the continuum of 'little c' to 'big c' creativity (and thus linking to scientific creativity for both students and professional scientists), playing with possibilities is important. This is clearly featured within IBSE as illustrated in Figure 1, as throughout, students engage with questions that ask them what it is possible to investigate, how it might be possible to gather evidence that would answer their questions, what that evidence tells them and thus what it is now possible to do and think about as a result. In terms of pedagogy, this implies that the responsibility of the educator working with students using IBSE approaches is to hold open a space in which they can play with possibilities, suitably scaffolded to understand what is possible, feasible, safe and ethical.

Teachers doing this thus offer the possibility for scientific creativity to emerge in and through their interactions with the students, in a manner parallel to the positioning of education in the 'gap' – the relation – between student and educator as proposed by Biesta (2004). Biesta would also argue that such education-in-relation is the distinction between education and training:

applying this distinction to science education and creativity leads us to suggest that although it is possible to 'train' students in scientific knowledge and processes through highly structured and guided means, education for scientific creativity is only possible through relational education of the kind highlighted in this literature review, exemplified within science in IBSE approaches where students have the opportunity to experiment with possibilities.

The above discussion of IBSE has focused primarily on how it might be developed within a school classroom context. However, recently, the Maker Movement (Halverson and Sheridan, 2014), has demonstrated more potential uses of IBSE in broader contexts. Due to its perceived potential as a driver of creativity, excitement, and innovation (Honey and Kanter, 2013), the maker movement has shown a rapid increase in popularity in Science Education. As Bevan et al. (2014) argue, making is promoted as advancing entrepreneurship, developing science, technology, engineering, and mathematics (STEM) workforce, and supporting compelling inquiry-based learning experiences for young people. In addition, Moote et al. (2013) introduce the CREativity in Science and Technology (CREST) scheme, which is a student-run science project supported by the science, engineering, and technology network. It is currently being implemented in schools across the United Kingdom to increase student engagement and motivation in science. The investigation of the approach shows that it can contribute to students' self-regulation abilities as well as their motivations. CREST projects regularly take place outside lesson time and draw together a range of disciplinary and out-of-school learning contexts, thus demonstrating the broader contextual possibilities within the IBSE framework of pedagogical approaches that can be harnessed to open a space for creativity in science education. A range of digital technologies may also be adopted both within IBSE and beyond as enabling contexts that have the potential to support creative science teaching and learning, and it is to this literature that we now turn.

3.3.3 Use of Technology to support creative science teaching and learning

The first context in which studies have shown that ICT environments can support students' learning in ways that link to creative education is in their potential facilitation of dialogue and collaboration. As highlighted above, collaboration has been identified as a key aspect of creative

education across a range of studies both within and beyond the discipline of science. Similarly, the concept of 'Living Dialogic Spaces' (Chappell and Craft 2011) highlights the importance of dialogue in creativity. Wegerif's work explores the potential of dialogic pedagogies in supporting learners' thinking and how technology might help develop this potential (Wegerif, 2012; Wegerif (2010). Technology-supported collaborative dialogue has been studied in the context of science education by Pifarre et al. (2012), who suggest that ICT environments such as wikis may help raise students' awareness of key collaborative scientific processes in IBSE. Using different technologies to explore similar skills, the Metafora project saw Smyrnaiou et al. (2012) exploit computer modelling, in the form of exploring, designing and building computer models of complex scientific phenomena. They conclude that working collaboratively with constructionist game microworlds that are designed to invite students to explore the fallible model underpinning the game and change it so as to create a new game, may provide students opportunities to bring into the foreground their conceptual understandings.

As well as offering alternative approaches to learning within class in ways that can contribute to creative teaching and learning, other studies have explored the ways in which technologies can enable students to engage with the work of professional scientists through accessing and analyzing real data and through virtual experiences in real laboratories. For example, Kourkoumelis and Vourakis (2014) describe an interactive tool for analysis of data from the ATLAS experiment taking place at the world's highest energy particle collider at CERN. They introduce the tool, called HYPATIA/applet, that enables students of various levels to become acquainted with particle physics and look for discoveries in a similar way to that of real research. Vourakis (2014) deploys the same tool to introduce the cutting edge of modern research to school physics rather than using more traditional school contexts and content. These researchers have also used virtual visits, science cafes and visits to CERN exposition with the purpose of investigating effective IBSE, concluding that a workshop where the students are introduced to one of the large LHC experiments, followed by a virtual visit to the experiment's Control Room and the opportunity to perform interactive analysis of real data is an effective approach to using such tools to engage students and support their science learning. In terms of scientific creativity, the opportunity to work with real data, and real scientists, is likely to enhance students' understanding of both the role of creativity within science and offer them opportunities to think

differently about novel ideas – playing with different possibilities – as a result of engaging with the discipline of science in a different contextual environment that the school lab setting.

3.3.4 Issues of Assessment in Creative science teaching and learning

Where learning is open-ended, novel or creative, how to assess such learning remains a vexed question. Given the importance of assessment of and for learning within current educational systems across Europe and internationally, not least within a high-profile subject such as Science, this is an issue to which we must now turn. Assessment of pre-defined scientific learning objectives, whether related to content or skills, is relatively straightforward. Where what is to be learned is, by definition, uncertain at the outset, strategies for assessment become much more challenging.

It has been argued in the literature that providing formative feedback contributes to pupils' development of creativity more effectively. Similarly, Lucas, Claxton, and Spencer (2013) argue that formative assessments can help teachers be more precise and confident about assessing students' creativity as well as helping students be able to better understand what it is to be creative. However, formative assessment valuing creative dispositions is not at the forefront of the neo-liberal performativity culture that is increasingly permeating national education policies (this is currently a particularly strong trend in the UK). As Craft (2008) puts it "the powerful drive to raise standards and to make performance judgments about individuals and about schools, can be seen as being in tension with an almost equally powerful commitment to nurturing ingenuity, flexibility, capability" within national government education policies.

Educators wishing to use creative pedagogies to promote students' scientific creativity are therefore likely to find themselves having to negotiate this tension through the processes of assessment of the outcomes of their creative pedagogies in terms of both knowledge and skills, as well as in relation to creativity. In terms of Inquiry-based Learning, the challenge of assessment has been identified and explored within the EU funded SAILS project (Strategies for the Assessment of Inquiry Learning in Science). Focused around formative assessment approaches, the SAILS project has identified strategies for the assessment of a range of

cognitive and affective outcomes of IBSE: reasoning skills, scientific literacy, scientific knowledge, interest and motivation, attitudes and beliefs, and self-concept and future orientation. However, they note that the goals and aims of IBSE projects were identified in terms of 'assessable outcomes' by Csapo, Csikos, Korom, Németh, Blck, Harrison, van Kampen and Finlayson (2012).

Whether creativity is an 'assessable' outcome of science education remains a contested issue. It may be the case the science can learn from the Arts in the assessment of creativity. For example, Small (2009), in the context of judgement of personal responses to poetry, suggested that by evaluating outcomes across a continuum from the personal to the public, insight into the creative process in a way similar to the assessment of learning power (see Deakin Crick, 2009) might be achieved. Importantly, he argues for the need for 'teachers, as an integral part of inquiries, involve learners in co-designing criteria for evaluation', with the teacher and students having 'joint responsibility for assessing enquiry based learning and creative activity (Small, 2009: 269). This argument points towards the use of some strategies for peer and self-assessment of scientific creativity in dialogue with teacher assessment. This kind of approach might be beneficial in enabling science educators to negotiate the tension between assessment of learning outcomes in terms of the attainment of curricular knowledge, and the assessment of more intangible outcomes such as motivation and creativity.

By considering the purposes and pedagogies of creativity in relation to science education, with a focus on IBSE and the use of technologies as particular pedagogical approaches that have the potential to open a space for creative science teaching and teaching for scientific creativity, we have demonstrated both the potential strengths and challenges offered by engaging with this work in science education. We have argued for the rich opportunities offered within science pedagogy for teaching for creativity that the CREATIONs project will aim to explore and develop.

4. Learning from the CREAT-IT project

So we can see above the wealth of knowledge that has been generated in relation to the wider field of creativity in education, arts/science integration and partnership, and creativity in science education per se. The review now focuses in on the learning outcomes of the most closely related project to CREATIONs, CREAT-IT.

The CREAT-IT project developed both a theoretical framework for encouraging creativity in science education and a set of eight pedagogical principles. These are being used in the CREATIONs project as a foundational starting point as they have been tried and tested across Europe within the CREAT-IT project (see: Craft, Chappell, & Slade, 2014; Greenwood et al, 2014; Slade & Hennessy, 2014).

Therefore the CREATIONs project is applying and adapting the CREAT-IT theoretical framework. Figure 2 shows this framework as it has been configured for the CREATIONs project:

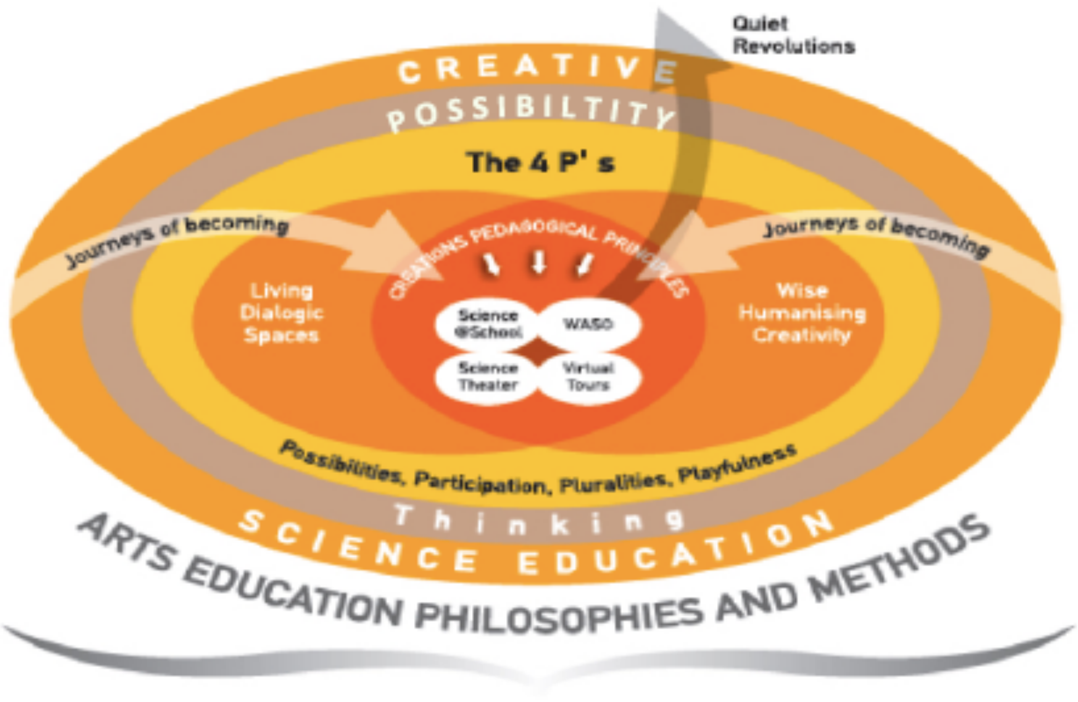

Figure 2: The configured CREATIONs theoretical framework

Creative science education is the main context within which the CREATIONs project will develop; this therefore forms the main outer circle of the figure. At the bottom of the figure, the arts education philosophy and methods is positioned as a 'holder' within which creative science education (as opposed to all science education) is being nurtured, grown or 'encultured' via arts and cultural practice. As we move in towards the centre of the figure we can see that one of the main drivers for CREATIONs creativity is possibility thinking for all involved. This concept was developed by Professor Anna Craft (2001), (For further information see: Burnard et al, 2006; Cremin, Burnard, & Craft, 2006; Chappell et al, 2008; Lin, 2010; Craft, McConnon, & Matthews, 2012; Geest, 2012; Craft, 2013; Craft et al, 2013; Pavlou, 2013).

Possibility thinking means being able to ask 'what if' and 'as if' questions. For example:

- What if I/we choose to explore this scientific question rather than that one…?;
- What if I/we use this arts approach to help me explore my question...?
- How can I/we imagine this as if I were…?;
- What happens if I as the teacher collaborate with that artist as if I…?.

Most recently the Possibility Thinking (PT) concept was extended into the study of social change in primary schools (Craft and Chappell, 2014). This new focus offers a context within which creative science teaching per se might function. It argues that in schools where head teachers and senior management have a creative approach to how their schools develop, creative education can also flourish.

PT per se will be strongly encouraged in the way the CREATIONs pedagogic principles are ultimately employed in order to help learners and adult professionals imagine new ideas in science education; to shift from 'what is' to new possibilities of 'what might be'. As we move in another layer towards the centre of the figure, we can see four key defining features of CREATIONs classroom environments. These are the 4Ps of engagement in creative science education (Craft, 2011, Craft, 2015):

- **Pluralities**: opportunities for students and teachers to experiment with many different places, activities, personal identities, and people
- **Possibilities**: opportunities for possibility thinking, transitioning from what is to what might be, in open possibility spaces
- **Participation**: opportunities for students and teachers to take action, make themselves visible on their own terms, and act as agents of change
- **Playfulness**: opportunities for students and teachers to learn, create and self-create in emotionally rich, learning environments.

We then come closer to the heart of the CREATIONs figure and find WHC (wise humanising creativity) and LDS (living dialogic space). WHC has at its heart the relationship between the creator's identity and their creativity, so as they make, they are also being made (Chappell, with Craft, Rolfe and Jobbins, 2012; Chappell, Pender, Swinford and Ford, in press). It is grounded in the philosophical ideas of Merleau Ponty (1964) and his argument that creativity occurs in the space between the inside and the outside and when creators are stretched between these two, new ideas emerge. WHC is not only an individual activity, but also happens in collaboration with fellow learners, teachers and other adult professionals (artists, researchers). These individual and collaborative creative activities form part of a wider web of ethically-guided (Craft, Gardner and Claxton, 2008) communal interaction geared towards both helping children and young people become more creative scientists and assisting teachers in becoming more creative in how they teach science. For this reason WHC is positioned very close to the heart of the CREATIONs figure as it is one of the core aims of the CREATIONs pedagogic principles.

Alongside and integrated with WHC, is LDS, always a partner to WHC in terms of conceptualising ideas and developing practice. Living dialogic spaces are best created via creative learning conversations which at their simplest are about re-positioning power hierarchies, listening to the voices of all involved and then actioning the results of the conversations (Chappell and Craft, 2011). Again LDS is at the heart of the CREATIONs figure because its methods (participation, emancipation, working bottom up, debate and difference, openness to action, partiality, and acknowledging embodied and verbal modes of knowing) are fundamental to allowing WHC to

happen. Chappell et al, (2012) have evidenced the importance of dialogue at the heart of engaged, creative learning in the arts and it is this kind of dialogue that has been highlighted and applied within the CREATIONs approach. CREATIONs Demonstrators (see Work Package 3) will promote the idea of dialogue between people, disciplines, creativity and identity, and ideas. LDS theorizing emphasizes that this dialogue acknowledges and allows for conflict and irreconcilable difference. It might be argued that facilitating open discussion of the problems pupils are facing in understanding scientific concepts and in solving scientific problems is key to a pedagogy, which acknowledges their values, needs and expectations as citizens of European Society (Craft et al, 2014).

As detailed above all of these layers of conceptual ideas have been synthesised together not only to develop this CREATIONs figure and accompanying narrative but also to generate CREATIONs own set of unique working pedagogical principles. Hence the connector in the image between WHC and LDS, and the CREATIONs Demonstrators is these principles. The principles represent the unique way that the consortium ideas come together in order to underpin the CREATIONs Demonstrators pedagogies. These principles draw on those developed in CREAT-IT (Chappell, Black, Slade and Craft with Greenwood, in review).

Overarching the principles is the notion of professional wisdom which is respected and encouraged across all creative science education activity. It is vital that the aproach recognises practitioners' wealth of teaching and discipline knowledge and expertise. This is a deeply contextualized knowledge often informed by intuition, which needs to be in constant conversation with science ideas and theories. Practitioners cannot be viewed as 'information deliverers'. It is their professional wisdom that can make the science learning process creative and can engage children and young people in a meaningful ways. The connected principles are as follows:

1. **Individual, collaborative and communal activities for change**: practice can allow for all three ways of engaging in activities, and particularly in relation to communal engagement can take advantage of the shared identities within which participants will work, allowing for difference but with a shared creative process and purpose.

2. **Risk, immersion and play:** allowing for these three processes to filter across learning and recognize how pedagogy can assist in creating literal space as well as 'thinking' space for these to occur.
3. **Dialogue:** practice can allow for dialogues between people, disciplines, creativity and identity, and ideas. This dialogue needs to acknowledge embodiment (i.e. dialogue is not simply a verbal activity) and difference and allow for conflict and irreconcilable difference. It is important to facilitate open discussion of the questions generated by pupils (bottom up) and bring these into dialogue with live questions from professional science and science education (top down).
4. **Interrelationship of different ways of thinking and knowing:** the pedagogy allows space for different ways of thinking (e.g. problem-finding, problem-solving, exploring, rationalizing, reasoning, reflecting, questioning, experimenting) focused around shared arts/science threads or throughlines. At the arts/science interface it can also offer the space for three different ways of knowing (knowing that - propositional knowledge, knowing how - practical knowledge, knowing this - aesthetic or felt knowledge), as well as acknowledging the embodied alongside the verbal.
5. **Discipline knowledge:** understanding the importance of allowing space for the rigorous discipline knowledge of both the sciences and the arts is vital, as well as understanding the importance of materials relevant to those disciplines (e.g. their bodies, with props, with paper and pencil, with sculpting materials, with Bunsen burners and test tubes, with chemicals, with equations) and how creativity might interact with these disciplinary knowledge bases differently, albeit in the context of science education.
6. **Possibilities:** practice can allow for multiple possibilities both in terms of thinking and spaces, and know when it is appropriate to narrow or broaden these
7. **Ethics and trusteeship:** adult professionals and learners consider the ethics of their creative science processes and products and be guided in their decision-making by

what matters to them as a community, acting as 'trustees' of that decision-making and its outcomes.

8. **Empowerment and agency:** empowering pedagogies can allow both learners and adult professionals to gain a greater sense of their own agency and ability to express themselves, and to then know what to do with that in order to be more creative scientists and to develop more creative science teaching techniques. This means enabling pupil agency and encouraging children to try out (and critique) their own ideas and questions in investigations.

When applied within CREATIONs, of vital importance to nurturing *empowerment and agency, dialogue, individual, collaborative and communal activities* for change and *ethics and trusteeship* is rigorous *Discipline knowledge*. This means science discipline knowledge but it is also embedded in the principle of *Different ways of thinking and knowing* in the world, alongside those prioritised within the scientific realm which scientists must engage with in order to generate conversations between their ideas and those of the 'public' in order that a shared dialogue can be ongoing rather than a one way conversation. The principles of generating *possibilities* and *risk, immersion and play* are strongly connected to the interdisciplinary nature of the CREATIONs project, drawing on a familiarity with these concepts in arts and cultural activities.

Finally, within Figure 2 at the core of the proposed approach are the creative scenarios and school-based activities (CREATIONs Demonstrators) and the accompanying pedagogic principles. The aim of the project is to be able to describe and inform these scenarios via the inquiry and creative learning approaches synthesized by the end of this deliverable in order to generate innovative practice and creativity in science classrooms across Europe. Figure 2 therefore represents the CREATIONs' consortium understanding of how the theories and ideas can be synthesised together conceptually, uniquely for CREATIONs in order to achieve this.

Via this synthesis the consortium aims to contribute to developing creative young scientists and creative science teaching pedagogies. Embedded within this is the vitally important notion that

students and teachers are creating wisely and humanely, and that cyclical developments occur between their creativity and their identity. As they generate new ideas; this in turn generates change in them as 'makers'; they are also developing or 'becoming' themselves. Slowly, small changes accumulate to contribute to 'journeys of becoming' (shown developing across the layers in Figure 2). These individual journeys are incremental and accumulate together, embedded within an ethical awareness of the impact of creative actions on the group. Through this process small-scale creative changes or 'quiet revolutions' (Chappell and Craft with Rolfe and Jobbins, 2011) can take place for the group as a whole (shown as emerging from the heart of the CREATIONs activity).

In order to move from what was learned in the CREAT-IT project to the new framework developing within the CREATIONs project timeframe, Task 2.1 in CREATIONs not only focused on literature reviewing, but also on workshops discussing the CREAT-IT principles with experts from across Europe. The outcomes of these workshops are presented next, followed by the over-arching synthesis of this document into the new CREATIONs features.

5. Learning from the CREATIONS pan-European workshops

This section of the deliverable presents a synthesises of the workshops conducted across Europe in the winter of 2015. European partners in the UK, Serbia, Norway, Greece, Sweden and Switzerland conducted twelve workshops in total. A total of 223 participants attended 13 free 90 minute workshop. 24% of the participants came from Serbia, 23% from Greece, 21% from Norway, 11% from the UK, 10% from Sweden and 9% from Switzerland.

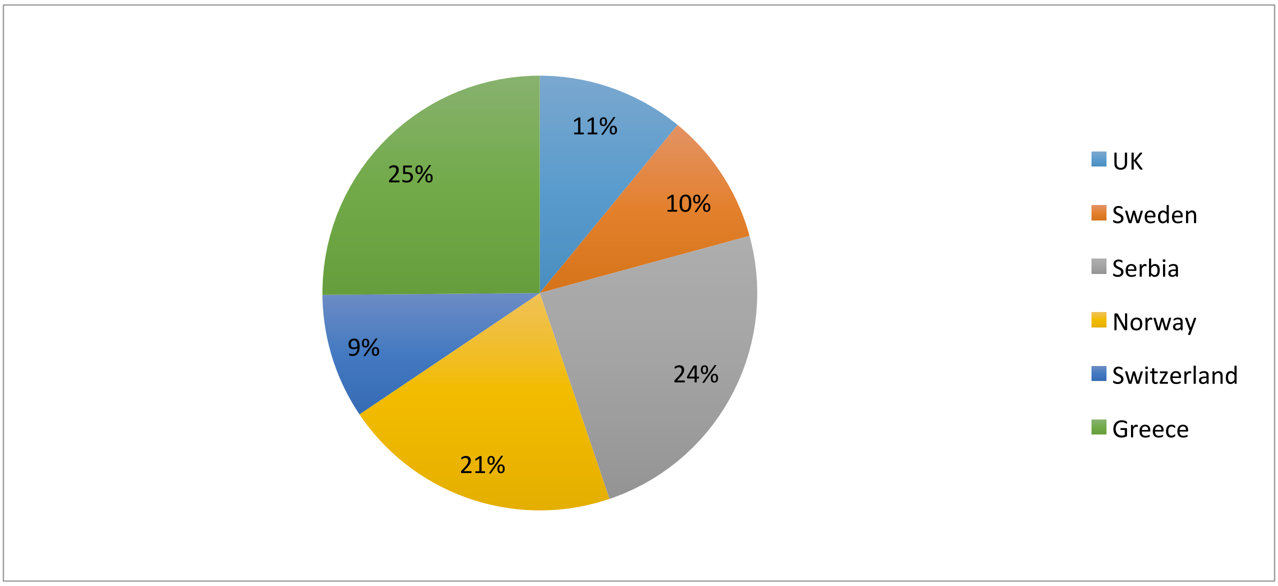

Figure 3: spread of participants that attended the CREATIONs workshops

The participants who attended the CREATIONs workshops were asked to choose a job descriptor title. Some participants chose more than one title to describe themselves and their profession; for the purpose of analysis only the first title they listed has been included in the analysis. Out of the 223 participants 43% classified themselves as a Science Educator, 43% as other, 11% as a Practitioner, 1% as a Specialist in cognitive psychology, sociology and/or learning sciences, 1% as a Teacher Educator and 1% considered themselves to be a Scientist.

The workshop was designed to create a living dialogic space via creative learning conversations in which all the participants were listened to and every voice was recognised and respected. The workshop was structured around the following aims

- To discover what creativity in science education means for the participants
- To discover what initiatives they were aware of that they think achieve this and engage students via different means including the arts and culture
- To discover what pedagogies the participants thought were key to using this approach.

This approach was utilised to model the kind of facilitation and pedagogy that the CREATIONs project itself is aiming to encourage. Each workshop host was provided with a digital recording sheet. Workshops were adapted to suit the cultural and educational context of the host country; in some cases partners chose to follow the guidelines exactly, but in others activities were altered or replaced with alternatives which the workshop leaders felt were more appropriate. Data from these activities has been considered thematically alongside the remainder of the data.

5.1 What is creativity in science education?

In this part of the workshop, participants were asked to consider the definition of creativity in science education derived from the CREAT-IT project (Craft, Chappell and Slade, 2014). They were given envelopes containing the elements of the definition separated out on to individual strips of paper, including some blank strips. These elements were:

- Purposive and imaginative activity
- Outcomes that are original and valuable in relation to the learner
- Generating ideas and strategies
- Individual and community
- Reasoning critically between ideas

- Producing plausible explanations and strategies consistent with the available evidence

They were asked to arrange these elements in any way that seemed appropriate to them, and also to consider any amendments that should be made to the definition. In one workshop it was decided by the participants that starting with a blank sheet rather than using the definition given would be more appropriate in terms of creativity; they felt that the definition given was overly reliant on jargon and was somewhat restrictive. At another workshop, the group decided to provide examples for each of the elements rather than amending them. In both cases, the responses have been considered and analysed together with those arising from the original task.

Arrangement of definition elements

Below is a summary of how the participants chose to arrange the elements according to four broad categories:

- Progressive: one element leading to another in a developmental fashion, demonstrated by arrows linking them
- Interdependent: elements were all of equal importance and could not be separated from one another (see figure 3)
- Hierarchical: one or more elements was considered to be of greater importance than others; this was represented in different ways
- Equal: elements were considered to be of equal importance

Of these, the interdependent model was the most popular.

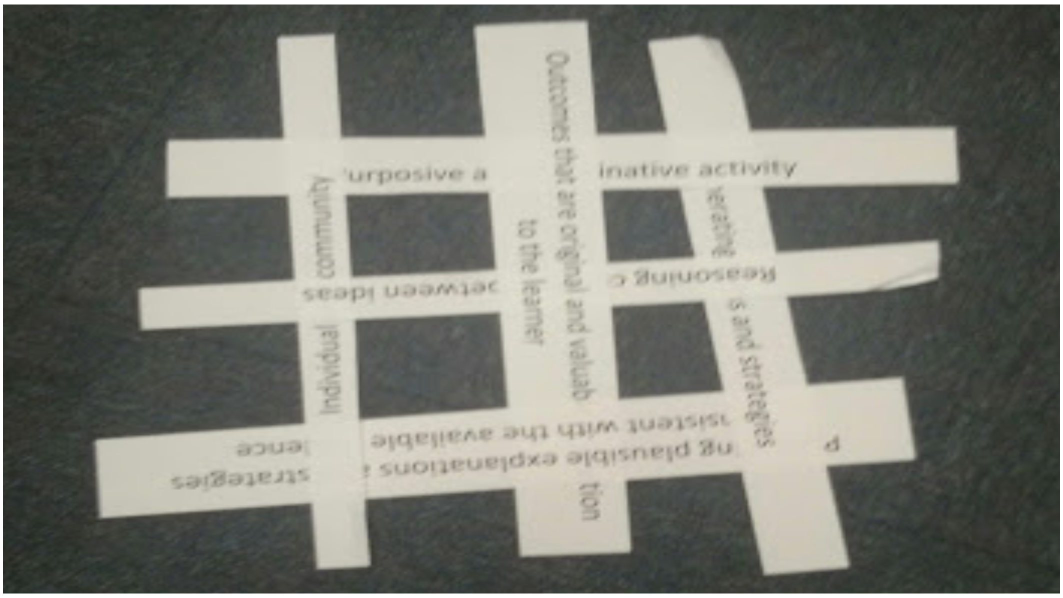

Figure 4: Interdependent model of creativity definition

Amendments to the definition

Few of the groups decided to exclude any of the elements; one group felt that 'individual and as a group' was not relevant, and another questioned the meaning of community.

There were several suggestions for amendments and changes to the existing elements. The most frequently occurring have been separated into broad categories. Participants felt that a definition of creativity in science education should encompass:

- Risk taking, permission to make mistakes and the acceptance of failure
- Emotional engagement
- A capacity to relate to the individual learner
- Interdisciplinarity
- Real life and functional contexts and applications of the outcomes

Participants also referred to aspects of creativity in science education such as awesomeness, excitement, mystery, curiosity, a sense of wonder, exploration and a spirit of enquiry, which could be categorized broadly as a philosophical ethos of science. Reference was also made to the broader context of science education in terms of the historical, social, cultural and community. Some participants considered the history of science and the work of scientists to be something that pupils needed to understand in terms of understanding the process of creativity in science.

Participants in several workshops referred to the differences between science in a school context and 'real life' science. They alluded to the pressures of curriculum restrictions, assessment and accountability and how this affected the potential to follow the spirit of curiosity and enquiry which characterise the work of scientists (see: Rocard, 2006; Archer and Tomei, 2014)

It was suggested that understanding of evaluation and assessment procedures could be added to the definition. The role of the teacher was also considered in terms of their capacity to guide the activity through effective questioning.

These workshop outcomes have therefore led to the following amended definition of creativity in science education to be used from hereonin within the CREATIONs project:

"Purposive and imaginative activity generating outcomes that are original and valuable in relation to the learner. This occurs through critical reasoning using the available evidence to generate ideas, explanations and strategies as an individual or community, whilst acknowledging the role of risk and emotions in interdisciplinary contexts".

5.2 Initiatives in creative science education.

Participants to the workshops were asked to suggest any initiatives in creative science education in their country. The emerging themes from the initiatives suggested were: one off events, suggestions to support further study, websites to support subject knowledge or topic teaching, particular people or companies with a particular science and arts connection.

First Lego League	http://www.firstlegoleague.org	Each year FIRST LEGO League releases a Challenge, which is based on a real-world scientific topic.
Bionet school	http:// bionet-skola.com	Online biology school
Electricity Symbols Kung Fu	https://www.youtube.com/watch?v=ex7xwaPha2I	Inspired by Phil Beadle's Punctuation Kung Fu, this Electricity Symbols Kung Fu to be used in the classroom
Dr Ben Still	http://pprc.qmul.ac.uk/~still/wordpress/	Dr Ben Still Physicist, Author and Science Educator
Bertha the dragon	https://scienceonstageuk.wordpress.com/2013/04/26/bertha-the-dragon/	Science show for primary school students

Table 1: Brief examples of initiatives gathered from CREATIONs workshop (please see Appendix 2 for further data)

5.3 Pedagogies in creative science education

To uncover the participants understanding about creative pedagogies in science education they were asked to produce a metaphor for the creative process in science education as a journey. In groups they were tasked to draw a large vehicle of their choice, they were then asked to annotate the image with the CREAT-IT principles and their own suggestions of pedagogies for the creative process in science education.

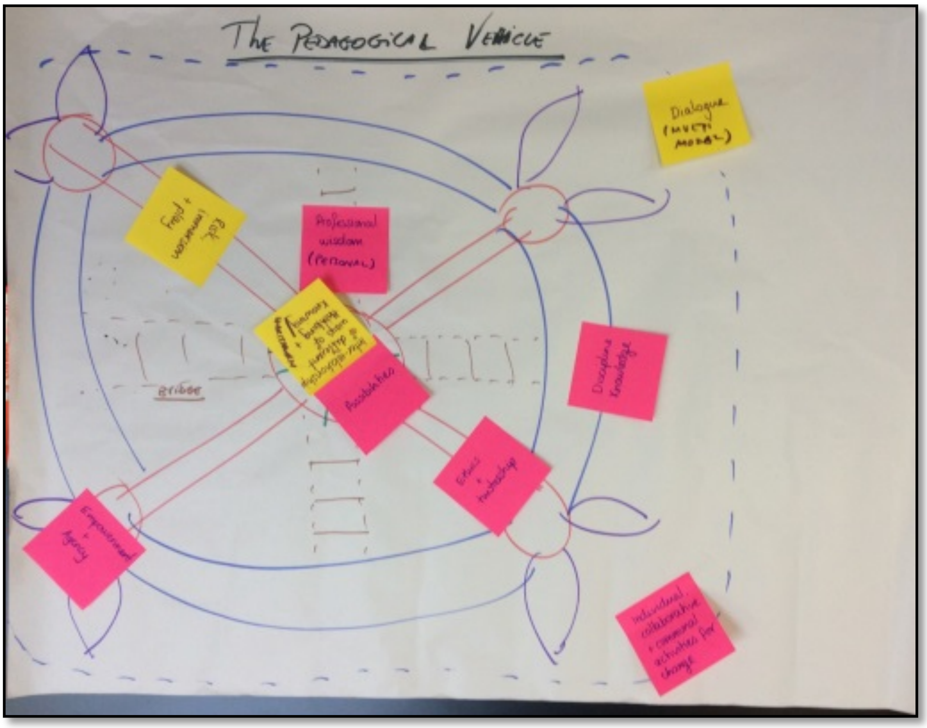

Figure 5: example from UK workshop

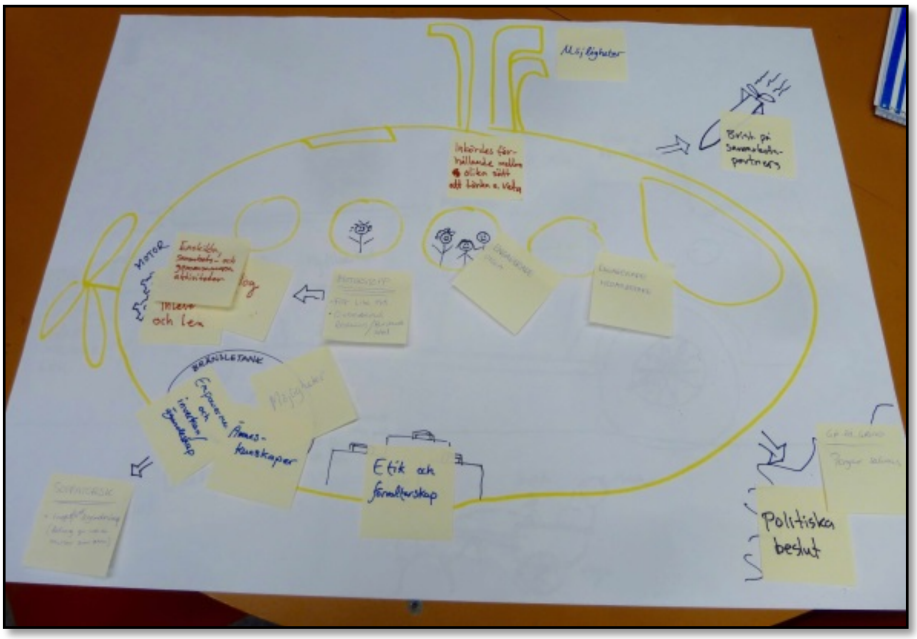

Figure 6: example from UK workshop

Once the data was synthesised and analysed, emerging themes across the pedagogical vehicles demonstrated that each group had considered a power source for their vehicles, had taken into consideration what drove or controlled their vehicle and what hazards they might face on their journey.

Power source – what fuels creative pedagogies?

The following principles were frequently used to illustrate some sort of power source that fuelled the vehicle.

- Individual, collaborative and communal activities for change
- Interrelationship of different ways of thinking and knowing
- Risk, immersion and play
- Empowerment and agency

The participants also made frequent reference to originality and failure as a power source and a number of the diagrams had these words added. During the Swiss workshop one group added the pedagogical principle Empowerment and Agency to the roots of a tree. When asked, to clarify why they had done this they commented that, as educators, they identify themselves more with the roots of the tree. As they feel responsible for empowering their students to develop their own tree of knowledge built on ethics and trust.

Steering – what drives, controls, guides creative pedagogies?

The following principles were frequently used to illustrate how the vehicle was controlled, guided or steered.

- Discipline knowledge
- Ethics and trusteeship
- Interrelationship of different ways of thinking and knowing

- Professional wisdom
- The participants also added the words: determination, perseverance and aspiration as words that can guide creative pedagogies

Hazards – What hazards might you face utilising this pedagogy?

None of the principles were listed as a potential risk, however the participants were able to identify a number of hazards they might face on their journey.

Fear was mentioned a couple of times also a lack of cooperation / interest between colleagues. The diagrams also highlighted a lack of resources and time whilst working in a pressurised environment. One group also commented how they felt uneasy about the words of know and knowing, explaining that as the world develops the understanding of things would change, which affects the status of knowledge.

Across every diagram dialogue was frequently selected to represent all of the emerging themes, it was seen as a power source, as something that can guide and steer creative pedagogies and therefore a lack of dialogue could become a hazard. As one group commented, dialogue between the arts and science must be consistent and frequent; they covered their space ship in an invisibility cloak to represent dialogue as it would permeate everything.

Overall, the workshops were well received, in particular one participant wrote to say that she had "met some interesting people with very different and exciting experience to share."

6. Synthesised CREATIONs 'features'

This final section synthesises what has been gleaned from the above literature review, workshop outcomes and previous projects to collate together the CREATIONs features of creativity in science education and inquiry learning. These features capitalise on developments in the area since the CREAT-IT project was initiated which have seen the 'STEM to STEAM' (science, technology, engineering and maths to science, technology, engineering, *arts* and maths) agenda take a much stronger hold in education across Europe and beyond. This can be seen internationally for example in the writing of Chappell et al (in review), Rabalais (2014) and Daugherty (2013), and in the work of organisations like 'STEMtoSTEAM'[2] and 'STEAMnotSTEM'[3].

Before detailing the CREATIONs features it is important to emphasise that they should be read in the context of the amended CREATIONs definition of creativity in science education (see section 5 for amendment details). This is now:

'*Purposive and imaginative activity generating outcomes that are original and valuable in relation to the learner. This occurs through critical reasoning using the available evidence to generate ideas, explanations and strategies as an individual or community, whilst acknowledging the role of risk and emotions in interdisciplinary contexts'.*

While the definition clearly focuses on creativity in science education in relation to the learner, we should step back to also acknowledge the teacher's creativity too. In the literature and practice, we can see the distinction between a focus on pedagogy ('creative teaching' or 'teaching creatively') and a focus on learning ('teaching for creativity'). Although these have been distinguished, setting them apart is perhaps not useful; it is more helpful to focus on the interaction of teachers' and students' creativity. McWilliams (2008) and Biesta's (2004) work is particularly pertinent here. McWilliams argues for a 'meddling in the middle' approach to creative education where teachers engage in the dynamic of learning with learners. They bring their own creativity and 'not knowing' into the relationship by valuing uncertainty, encouraging and

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[2] http://stemtosteam.org

[3] http://steam-notstem.com

modelling risk-taking alongside students and actively co-evaluating with students what is occuring.

Another angle on this, is to consider creative education as occuring in the relational interaction between teachers and students. Biesta (2004) argues that we should think of pedagogy as relational, that is, that education happens in the relational interaction between teachers and learners, not via a process of knowledge transmission. We would argue that the CREATIONs features can be successfully applied if this is done from a place where teachers are seen as engaging in the dynamic of learning with learners, and where the act of creative education is viewed as relational rather than as about the distinct component parts of teacher and learner exchanging information.

Finally, as with the CREAT-IT principles, the CREATIONs features begin with a continual respect for professional wisdom. This means recognising practitioners' wealth of teaching and discipline knowledge and expertise. It is a deeply contextualized knowledge often informed by intuition, which needs to be in constant conversation with science ideas and theories. As in Biesta's (2004) writing, practitioners cannot be viewed as 'information deliverers'. It is their professional wisdom that can apply the features of creative education to make the science learning process creative and to engage themselves, children and young people in a meaningful ways.

And so to the CREATIONs features of creative education which have been adapted and developed from the rest of this deliverable. The main developments from the CREAT-IT principles are merging *Discipline Knowledge* and *Interrelationship of different ways of thinking and knowing* into *Interdisciplinarity*; the addition of *Balance and Navigation*; together with amendments to the supporting definitions of the other features. They now read as follows:

1. **Dialogue**: practice can allow for dialogues (questions leading to answers leading to questions...) between people, disciplines, creativity and identity, and ideas. This dialogue needs to acknowledge embodiment (i.e. dialogue is not simply a verbal activity) and difference and allow for conflict and irreconcilable difference. It is important to facilitate open discussion of the questions generated by students (bottom up) and bring these into dialogue with live questions from professional science and science education (top down).

2. **Interdisciplinarity** This is grounded in the *interrelationship of different ways of thinking and knowing* which means allowing space for different ways of thinking (e.g. problem-finding, exploring, reasoning, reflecting, questioning, experimenting) around shared arts/science threads or throughlines. At the arts/science interface there are also three different ways of knowing (knowing that - propositional knowledge, knowing how - practical knowledge, knowing this - aesthetic or felt knowledge), as well as acknowledging the embodied alongside the verbal. Within interdisciplinarity it vital to respect rigorous science and art *discipline knowledge*, as well as understanding the importance of discipline-relevant materials (e.g. bodies, props, paper and pencil, sculpting materials, Bunsen burners and test tubes, chemicals, equations) and how creativity might interact with these disciplinary knowledge bases differently, albeit in the context of science education.
3. **Individual, collaborative and communal activities for change**: practice can allow adult professionals and students to engage at all three levels, and particularly in relation to communal engagement can take advantage of the shared identities within which participants will work, allowing for difference but with a shared creative process and purpose. Employing available tools such as technology (e.g. social media, online resources and sharing facilities and novel science-focused technologies) to support this process, can also build on what is possible creatively face to face.
4. **Balance and navigation**: practice can generate creativity in education by balancing control and freedom, structure and openness, stepping back and stepping in, and prior knowledge and new knowledge; practice can also acknowledge the common educational tensions and dilemmas of accountability/assessment, marketisation and resource/time pressures and *navigate* these with creativity rather than pursuing a creativity Versus performativity mentality
5. **Empowerment and agency**: empowering pedagogies can allow both learners and adult professionals to gain a greater sense of their own agency and ability to express themselves, and to then know what to do with that in order to be more creative scientists and to develop more creative science teaching techniques. This means

enabling pupil agency and encouraging children to try out (and critique) their own ideas and questions in investigations.

6. **Risk, immersion and play**: allowing for these three processes to happen across teaching/facilitation and learning and recognizing how pedagogy can assist in creating literal space as well as 'thinking' space for these to occur. This can be achieved by creating a trusting space in which mistakes are possible and there is no fear of failure.
7. **Possibilities**: practice can allow for multiple possibilities both in terms of thinking and spaces, and know when it is appropriate to narrow or broaden these in the context of asking 'what if' questions
8. **Ethics and trusteeship**: adult professionals and learners consider the ethics of their creative science processes and products and are guided in their decision-making by what matters to them as a community, acting as 'trustees' of that decision-making and its outcomes.

To assist with the fact that the creative education features are not presented in any intentional hierarchy above, they are also shown in Figure 7 below with all of the features connected via professional wisdom.

Figure 7: CREATIONs features of creative education

It is important to remember the importance of inquiry learning here. To this end this section culminates with an explication of how these features work within a science inquiry learning process. It must be noted that this is *one way* that the creative education features and inquiry learning might interact, not *the way.*

Given the breadth of IBSE frameworks available in the literature, in order to exemplify one approach to drawing on the CREATIONs features in relation to IBSE, we have chosen to use the recent synthesis of the essential features of IBSE produced by the PATHWAYs project (Bogner, Schmid and Dieser 2013: 11). Although these are presented in a tabular format, the process is in practice highly organic, with students and teachers in dialogue with each other drawing on a range of personal and disciplinary knowledge to thread across and between these features.

Essential features of IBSE	Interaction with CREATIONs Features
QUESTION: students investigate a scientifically oriented question	Students pose, select, or are given a scientifically oriented question to investigate. *Balance and navigation* through *dialogue* aids teachers and students in creatively navigating educational tensions, including between open and structured approaches to IBSE. Questions may arise through *dialogue* between students' scientific knowledge and the scientific knowledge of professional scientists and science educators, or through *dialogue* with different ways of knowledge inspired by *interdisciplinarity* and personal, embodied learning. *Ethics and trusteeship* is an important consideration in experimental design and collaborative work, as well as in the initial choice of question.
EVIDENCE: students give priority to evidence	Students determine or are guided to evidence/data, which may come from *individual, collaborative and communal activity* such as practical work, or from sources such as data from professional scientific activity or from other contexts. *Risk, immersion and play* is crucial in *empowering* pupils to generate, question and discuss evidence.
ANALYSE: students analyse evidence	Students analyse evidence, using *dialogue* with each other and the teacher to support their developing understanding.
EXPLAIN: students formulate an explanation based on evidence	Students use evidence they have generated and analysed to consider *possibilities* for explanations that are original to them. They use argumentation and *dialogue* to decide on the relative merits of the explanations they formulate, *playing* with ideas.
CONNECT: students connect explanations to scientific knowledge	Students connect their explanations with scientific knowledge, using *different ways of thinking and knowing* ('knowing that', 'knowing how', and 'knowing this') to relate their ideas to both disciplinary knowledge and to *interdisciplinary* knowledge to understand the origin of their ideas and reflect on the strength of their evidence and explanations in relation to the original question.
COMMUNICATE: students communicate and justify explanation	Communication of *possibilities*, ideas and justifications through *dialogue* with other students, with science educators, and with professional scientists offer students the chance to test their new thinking and experience and be *immersed* in a key part of the scientific process. Such communication is crucial to an *ethical* approach to working scientifically.
REFLECT: students reflect on the inquiry process and their learning	*Individual, collaborative and community-based* reflective *activity for change* both consolidates learning and enables students and teachers to balance educational tensions such as that between open-ended inquiry learning and the curriculum and assessment requirements of education.

Table 2: Essential features of IBSE and how they interact with the CREATIONs features

The narrative in Table 2 demonstrates how the CREATIONs features are closely thread throughout, processes of Inquiry-based Science Education. The appearai the features numerous times, particularly the importance of dialogue, shows h embedded within IBSE as a relational pedagogy. Figure 6 shows the CREATION IBSE visually represented as a mobius strip to indicate their inter-relationsh important from here that this interrelationship is emphasised and practiced within demonstrators and workshops.

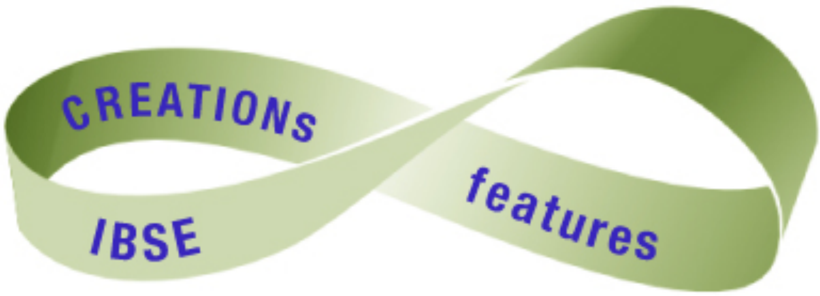

Figure 8: The interrelationship of IBSE and CREATIONs features

Teachers have choices about the extent to which an inquiry is student-led or te and it would often appear to be the case that there is greater opportunity fo teachers to 'be creative' where IBSE is at the open, student-led end of the spect as demonstrated in the figure, through teacher-student dialogue and an e: students will have agency in their interpretation of questions and evidence, it is balance to be found between openness and structure which maintains creative p in a more strongly teacher-directed inquiry. The translation of the CREATION practice through IBSE and the CREATIONs demonstrators will be taken for deliverables.

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8. Appendices

CREATIONs: Workshop Guidance

These activities draw on the idea of the workshop creating a living dialogic space via creative learning conversations in which all participants are listened to and have a voice.[1] *This approach has been used in order to model the kind of facilitation and pedagogy that the CREATIONs project itself is aiming to encourage. Each workshop should contain 15 – 20 people from across the target groups. A digital recording sheet has been provided; please input data directly into this sheet, including photos where possible.*

Information gathered in the workshop will be used to inform the writing of a CREATIONs report; participants can have access to the information gathered if they so wish. Please make sure you tell the participants this at the beginning of the session, and ensure you take contact details where appropriate.

Aim: to get people thinking and talking about:

- what creativity in science education is for them
- what initiatives they are aware of that they think achieve this and engage students via different means including the arts and culture
- what pedagogies they think are key to this

1 Warm up (20 mins)

1 Please sit down at your table (suggestion is 4 – 5 people around a table) organising yourselves in alphabetical order around the table according to your first name

2 Once you're sat down please introduce yourself and say ONE sentence each about your role in relation to science education

3 Temperature taking - see the middle of the table as very hot/positive and the edge of the table as very cold/negative. Place your hand on the table in terms of how positive/negative you currently feel about the state of creativity in science education. Briefly share your reasons for where your hand is.

Facilitation: keep people to one sentence for the first part of this task otherwise it will take too long. Keep discussion for 3 focused on why they put their hand where they did – this does not need to be done individually but can be done in clusters – taking examples of reasons from those who are near the centre/further away from the centre.

Documentation: The facilitator should take a photograph of where the hands are placed and note key examples digitally on the documentation sheet.

2 What is creativity in science education? (20 mins)

In groups of 4 – 5 workshop participants rank or arrange key elements that make up the definition of creativity in science education. Remember the definition will be used across Europe, across primary and secondary education so it needs to be abstract enough to encompass multiple forms of practice. The current suggestion from the end of the CREAT-IT project is:

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[1] Chappell, K., & Craft, A. (2011) Creative learning conversations: producing living dialogic spaces. *Educational Research.* 53(3) pp. 363–385. This workshop process has been designed by the University of Exeter CREATIONs team. For further information please contact Kerry Chappell or Hermione Ruck Keene: k.a.chappell@exeter.ac.uk or H.RuckKeene@exeter.ac.uk

"Purposive and imaginative activity generating outcomes that are original and valuable in relation to the learner. This occurs via generating ideas and strategies as an individual or community, reasoning critically between these and producing plausible explanations and strategies consistent with the available evidence".

Elements separated out on slips of paper are:

Purposive and imaginative activity

Outcomes that are original and valuable in relation to the learner

Generating ideas and strategies

Individual and community

Reasoning critically between ideas

Producing plausible explanations and strategies consistent with the available evidence

Conclusion of activity - How close does each group feel the creativity in science education definition is for them? What amendments, if any, would they make?

Facilitation: this needs an envelope with the words below written on slips of paper, as well as some spare slips – the aim is to allow everyone in the group a voice – techniques to help this include asking each person to read out an element of the definition, and working round the group asking people to contribute briefly in turn rather than having an open floor speaking policy, where more dominant voices may take over. Re ranking or arranging, participants may want to place the elements in a top down list, spanning out from a central point where centre is most important – this is open to interpretation by the group.

Documentation: The facilitator should take notes, digitally on the documentation sheet, regarding major amendments to the definition being offered. They may also wish to note any major differences of opinion. And also take a photograph of the final arrangement of the elements of the definition.

3 Initiatives in creative science education (20 minutes)

Working digitally in pairs or threes, participants share examples of good practice re creativity and engagement in science education under the following headings:

IBSE or inquiry-based

Arts or culture-based

Others?

For each initiative, need to clearly obtain:

Name

Web address

Any particular science focus

Other disciplinary/cultural/digital elements

Bearing in mind the definition above – why do they think the initiative is:

1. Creative
2. Leads to better engagement in science education

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Facilitation: encourage participants to talk and record their discussions in pairs for 10 minutes either on their own laptops/tablets or on paper and then take a photograph, and to highlight one initiative from their discussion which they think is most creative and engaging in terms of science education. For the last 10 minutes of this task the pairs share their chosen initiative with the group. Be clear that the information shared in this section can be made available to participants soon after the workshop.

Documentation: The facilitator should make sure whatever digital tool is being used that all elements are recorded for each pair where necessary to save them having to chase up key details later.

4 Pedagogies in creative science education (25 mins)

Participants work in 5s. Working with the metaphor of the creative process in science education as a journey, ask each 5 to draw a large vehicle of their choice on a piece of flipchart paper (bus, bicycle, aeroplane etc). Then ask them to use the 8 provided post-it notes to annotate the image with the key pedagogies for the creative process in science education. Provide spare post-it notes for them to add their own pedagogies too drawing on their own practice or theoretical knowledge. The CREAT-IT principles will need explaining before they begin. Use the first 15 minutes to explain the pedagogies and have them develop their image/post-its. Use the last 10 minutes for the groups to briefly share their positioning of the CREAT-IT pedagogies, their new pedagogies, journey end and break downs.

Facilitation: You will first need to explain the 8 CREAT-IT pedagogic principles (details attached). For the annotation exercise, prompt questions might include – Which pedagogies are the engine of creativity in science education? What pedagogies do you need in your boot to bring out when appropriate? Who are the key people in the vehicle that you're using the pedagogies with? Is there anything else that you might want to have on the journey e.g. on the roof rack? What might cause you to break down on your journey (encourage them to draw this as well as write)? Dependent on your group and cultural context, you may wish to develop your own metaphor for this exercise which encourages people to discuss and document the 3 key elements re their opinion of the principles, any new pedagogies and any issues that they raise.

Documentation: The facilitator should make digital notes either during or after the workshop picking up on key discussion points including:

- *whether all groups are able to place all 8 CREAT-IT principles*
- *what new pedagogies each group adds (including key references where appropriate)*
- *and what breakdown causes are.*

Please also take a picture of each piece of flipchart paper.

5 Wrap up (5 mins)

Thank all participants for their contributions. In a circle, or arrangement where everyone can see each others faces ask all the participants to offer one word summing up how they have felt about the workshop, and one sentence saying what they will take away from it.

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Documentation sheet: Please remember to record for all groups in relation to each activity – please save this sheet as a separate document for each workshop that you carry out. Boxes will expand as you type into them.

Workshop facilitator:	**Workshop date, time and venue:** **Number of participants:** **(Please also complete the separate sheet detailing participants names and categorisation)**	
ACTIVITY ONE: WARM UP	**Record reasons for the placement of hands**	
ACTIVITY TWO: DEFINITIONS	**Amendments to the definition**	**Differences of opinion**
ACTIVITY THREE: INITIATIVES	**Workshop participants should record their ideas digitally – either on their own laptops/tablets or on paper and then take a photograph. Please transfer their ideas to this column or include them as a separate document.**	

This workshop process has been designed by the University of Exeter CREATIONs team. For further information please contact Kerry Chappell or Hermione Ruck Keene: k.a.chappell@exeter.ac.uk or H.RuckKeene@exeter.ac.uk

ACTIVITY FOUR: PEDGAGOGIES	**Key discussion points** ○ ***whether all groups are able to place all 8 CREAT-IT principles*** ○ ***what new pedagogies each group adds (including key references where appropriate)*** ○ ***and what breakdown causes are.***

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This workshop is the start of a CREATIONS networking and information sharing group for the participants and as such it would be useful to have your contact details. Please record them below together with a categorisation of your role in science education (see list in column 2) if you are happy to share them with others.

Name	**Role in science/education?** (science educator, science curricula developer, teacher educator, scientist, practitioner, specialist in cognitive psychology, sociology and/or learning sciences?)	**Email address**

This workshop process has been designed by the University of Exeter CREATIONs team. For further information please contact Kerry Chappell or Hermione Ruck Keene: k.a.chappell@exeter.ac.uk or H.RuckKeene@exeter.ac.uk

Resources:

Flipchart paper

Post-its

Coloured pens

Ranking statements – to be printed and cut out x 4 for use by up to 4 groups

Purposive and imaginative activity

Outcomes that are original and valuable in relation to the learner

Generating ideas and strategies

Individual and community

Reasoning critically between ideas

Producing plausible explanations and strategies consistent with the available evidence

CREAT-IT principles – see following page

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CREAT-IT Pedagogical Principles

Professional wisdom is respected and encouraged across the principles: it is vital that the aproach recognises practitioners' wealth of teaching and discipline knowledge and expertise. This is a deeply contextualized knowledge often informed by intuition, which needs to be in constant conversation with science ideas and theories. The connected principles are as follows:

1. **Individual, collaborative and communal activities for change**: practice can allow for all three ways of engaging in activities, and particularly in relation to communal engagement can take advantage of the shared identities within which participants will work, allowing for difference but with a shared creative process and purpose.
2. **Risk, immersion and play**: allowing for these three processes to filter across learning and recognize how pedagogy can assist in creating literal space as well as 'thinking' space for these to occur.
3. **Dialogue**: practice can allow for dialogues between people, disciplines, creativity and identity, and ideas. This dialogue needs to acknowledge embodiment (i.e. dialogue is not simply a verbal activity) and difference and allow for conflict and irreconcilable difference. It is important to facilitate open discussion of the questions generated by pupils (bottom up) and bring these into dialogue with live questions from professional science and science education (top down).
4. **Interrelationship of different ways of thinking and knowing**: the pedagogy allows space for different ways of thinking (e.g. problem-finding, problem-solving, exploring, rationalizing, reasoning, reflecting, questioning, experimenting) focused around shared arts/science threads or throughlines. At the arts/science interface it can also offer the space for three different ways of knowing (knowing that - propositional knowledge, knowing how - practical knowledge, knowing this - aesthetic or felt knowledge), as well as acknowledging the embodied alongside the verbal.
5. **Discipline knowledge**: understanding the importance of allowing space for the rigorous discipline knowledge of both the sciences and the arts is vital, as well as understanding the importance of materials relevant to those disciplines (e.g. their bodies, with props, with paper and pencil, with sculpting materials, with Bunsen burners and test tubes, with chemicals, with equations) and how creativity might interact with these disciplinary knowledge bases differently, albeit in the context of science education.
6. **Possibilities:** – practice can allow for multiple possibilities both in terms of thinking and spaces, and know when it is appropriate to narrow or broaden these
7. **Ethics and trusteeship**: adult professionals and learners consider the ethics of their creative science processes and products and be guided in their decision-making by what matters to them as a community, acting as 'trustees' of that decision-making and its outcomes.
8. **Empowerment and agency**: through empowering pedagogies, CREAT-IT can allow both learners and adult professionals to gain a greater sense of their own agency and ability to express themselves, and to then know what to do with that in order to be more creative scientists and to develop more creative science teaching techniques. Enabling pupil agency and encouraging children to try out (and critique) their own ideas in investigations were also key factors to emerge from the survey, thus emphasizing the importance of this principle.

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Name	Website	Description
Anthology Of Serbian Literature Project	antologijasrpskeknjizevnosti.rs	Digitalization project of the most important works of Serbian literature Anthology of Serbian Literature makes easily available for reading capital works of Serbian literature to broad public, all over the world.
Bertha the dragon	https://scienceonstageuk.wordpress.com/2013/04/26/bertha-the-dragon/	Science show for primary school students
Bionet school	bionet-skola.com	Online biology school
Bright Club	http://www.brightclub.org	Bright Club started as collaboration between comedy promoters One Green Firework, music promoters Duel in the Deep and UCL, London's Global University.
Coursea	coursera.org	Online courses
Creative Encounters: New conversations in science, education and the arts	http://www.wellcome.ac.uk/About-us/Publications/Books/WTD028351.htm	An essential guide to the emerging educational landscape of the 21st century, 'Creative Encounters: New conversations in science, education and the arts' explores the many opportunities and questions provided and prompted by collaborations between artists, educators and scientists.
Dr Ben Still	http://pprc.qmul.ac.uk/~still/wordpress/	Dr Ben Still Physicist, Author and Science Educator
DzDigital	digitalnaskola.rs	Digital classrooms in Serbia

classroomdz		
edx	edx.org	Free online courses
Electric car	N/A	Engineering, Robotics
Electricity Symbols Kung Fu	https://www.youtube.com/watch?v=ex7xwaPha2I	Inspired by Phil Beadle's Punctuation Kung Fu, this Electricity Symbols Kung Fu to be used in the classroom
Embercombe Outdoor Education Centre	http://embercombe.org	Embercombe's outreach team specialises in delivering bespoke interactive projects with your children that brings your outdoor environment at school to life.
Energy saving programme		Energy & Environmental Science
Environmental sustainability	http://www.inspiringscience.eu	Environmental Science
Explore space	https://www.kulturdirekt.se/kulan/?p=org&id=19	Theatre Barbara was established in 2003. We play performances on its own stage and on tour around the country.
First Lego League	http://www.firstlegoleague.org	Each year FIRST LEGO League releases a Challenge, which is based on a real-world scientific topic.
Going Dark	http://www.fueltheatre.com/projects/going-dark	Sound & Fury use their innovative theatre vocabulary of immersive surround sound design, total darkness and imaginative lighting in Going Dark to reawaken our wonder at the cosmos and reveal how one

		man’s vision becomes illuminated by darkness.
Green School		Energy & Environmental Science, Physics, Chemistry
Highschool Kragujevac	prvagimnazija.edu.rs	School in the capital of Serbia
House of Science	http://www.vetenskapenshus.se	The House of Science is a leading resource of inspiration and knowledge in Stockholm. We are here for students of all ages from primary school to secondary school / high school levels as well as Their teachers
Jiggling Atoms	http://jigglingatoms.org/lectures/	This project about illustrating abstract concepts from the often surprising world of physics, we believe that in order to tackle this task, there is no need to become a physicist.
Kpeatnbh Wkoja	kreativnaskola.rs	Institute for Improvement of Education
Kulturhuset City Theatre	http://kulturhusetstadsteatern.se/English	Kulturhuset City Theatre – one of Northern Europe's largest cultural institutions is a public space for all people in Stockholm. The activities include libraries, theatre, debates, art exhibitions, film, dance and music.
KulturKontakt Austria	kulturkontakt.or.at	KulturKontakt Austria (KKA) is a European competence and resource centre for the core areas of education, cultural education with schools in Austria, international educational cooperation, and the Artists in Residence

		programme for artists from other countries.
Lab 13	http://www.ignitefutures.org.uk/ignition/lab-13/	A lab managed by young people for young people where they can experiment, play, invent, design, solve problems, explore, work alongside a scientist/designer/engineer in residence
Matematiranje	matematiranje.in.rs	Online maths course
Maths Makes Sense	https://global.oup.com/education/content/primary/series/maths-makes-sense/?region=uk	Richard Dunne's approach to mathematics engages learners through the systematic use of concrete objects, actions and language to make the abstract, symbolic language of mathematics accessible and enjoyable.
Mobiles phones and radiation		Engineering, Health sciences
My School Garden		Energy & Environmental Science, Physics, Chemistry
Paington Zoo	http://www.paigntonzoo.org.uk/about-us	The Zoo was founded in 1923 by Herbert Whitley
Phet Simulations	https://phet.colorado.edu	Interactive simulations for science and math
Physics Enchants [organized annually by GPS]	http://eef.gr/enimerosi/1018-fisiki-mageyei.html	Astroparticle Physics, Cosmology, Materials Physics, Environmental Science
Physics Kit Resources for teachers	http://ph.qmul.ac.uk/sites/default/files/Engagement/SEPnet_Lego%20teacher	This guide is designed to help you deliver the principles of particle and nuclear physics through engaging activities using Lego®

	%20resource_low%20res%20reference%20PDF%20as%20spreads.pdf	bricks.
Pismeni Zadaci	pismenizadaci.com	Asseing knowledge of mathematics
Potential difference Theatre	http://potentialdifference.weebly.com/	Potential Difference is a theatre company with a passion for creating new work that communicates complex theoretical ideas and their impact on the world around us.
Quantum art project	http://www.thequantumartproject.com	Artist Dennis Duolee interprets quantum physics on large canvases in collaboration with Stockholm University and Fysikum at AlbaNova (Stockholm Center for Physics, Astronomy and Biotechnology), creating a platform where art meets science.
Radoman Cvetičanin		
Rajak	rajak.rs	Online maths courses
Rambert Dance Company 'Constant Speed'	http://www.rambert.org.uk/explore/news-and-blog/blog/dance-writer-sanjoy-roy-is-asked-what-contemporary-dance-has-in-common-with-science/	The Institute of Physics invited Mark Baldwin to create a dance tribute to Einstein
Schools Build-a-Plane Challenge	http://aerosociety.com/Careers-Education/buildaplane	The SBAP-Challenge engages school pupils in providing young people in secondary schools to gain hands - on experience of the aircraft

		build process and the wider STEM subjects to encourage them in a career in the industry. - See more at: http://aerosociety.com/Careers-Education/buildaplane#sthash.yjKGZXFU.dpuf
Science Choreography	http://sciencechoreography.wesleyan.edu/about/project-history/	A collaboration of the Wesleyan Hughes Program in the Life Sciences and the Liz Lerman Dance Exchange
Science made simple	http://www.sciencemadesimple.co.uk/shows/busking	Presenters use simple science tricks to engage and excite small groups of people as they move throughout a festival venue
Science Show Off	http://www.scienceshowoff.org	It's a chaotic open mic night for scientists, science communicators, science teachers, historians and philosophers of science, students, science popularisers and anyone else with something to show off about science.
Slavica Gajić	mojainformatika.wordpress.com	Website dedicated to teaching computer
Slavica JurićMaja		
Slobodan Kaličanin	slobodankalicanin.weebly.com	This site is intended for my students and colleagues, especially young colleagues who are just starting to deal with the teaching profession.
Steiner Academy Exeter	http://www.steineracademyexeter.org.uk	Our vision is to provide diversity and educational choice to the people of Exeter within our all-through Steiner school,

		educating children from age 4 to 16
STEMfest	http://www.national-aquarium.co.uk/learning/stemfest	STEMfest for schools theatre at the aquarium is used for science demonstrations
Stevan Jokić	https://www.linkedin.com/in/stevan-jokic-3aa8761a	Researcher at Faculty of Technical Sciences and DunavNET LTD, Novi Sad, Serbia
Sudbury School	https://en.wikipedia.org/wiki/Sudbury_school	A Sudbury school is a type of school, usually for the K-12 age range, where students have complete responsibility for their own education, and the school is run by direct democracy in which students and staff are equals
Tekniska Museet	http://www.tekniskamuseet.se	Museum of Technology will develop and convey knowledge and experience of cultural heritage and thus provide perspectives on social development.
The Arts Sdcience Prize	http://www.artscienceprize.org/uk	The UK ArtScience Prize is a programme through which students develop innovative art and design ideas informed by concepts at the frontiers of modern science.
The Wandering Adventure Book	http://comeniusnevesjunior.blogspot.gr/2009/06/wandering-adventure-book-cover.html	A Comenius project (2008-10) in which students from all partner schools in 6 countries wrote short stories. Each chapter was written by the Polish, Lithuanian, Portuguese, Greek, Spanish and Romanian students

The world of particles	http://www.birmingham.ac.uk/schools/physics/outreach/MiniParticlePhysicsWorkshops.aspx	Mini Particle Physics Workshops for Primary Schools
Theatre and Experimental Physics		Physics and arts
Uci Slobodno	ucislobodno.com	Mathematics for primary schools
VEBCIKLOPEDIJA Hardware Web tools	vebciklopedija.zajednicaucenja.edu.rs	The largest catalogue of Web 2.0 tools in the Serbian language