D2.4 Professional Development of Educators: Considerations and Strategies

D2.4 Professional Development of Educators: Considerations and Strategies

Project Reference:	H2020-SEAC-2014-2015/H2020-SEAC-2014-1	**Editing:**	
		Hetherington, L.,	
		Ruck Keene, H.,	
		Chappell, K.,	
		Slade, C.	
Code:	Final	**Approved by:**	UoB, EPS
Version		**Process Owner:**	EXETER
Date:	18th March 2016		

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

The CREATIONS project has been funded with support from the European Commission under: H2020-EU.5., H2020-EU.5.a. Project reference: 665917

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, **D2.4 Professional Development of Educators: Considerations and Strategies** synthesises a range of previous findings from EU-funded projects and wider literature with an original survey to identify a) the perspectives on effective, creative science pedagogy and practice of a range of stakeholders, and b) good practice in the education and development of teachers in creative and inquiry-led pedagogies. These findings are drawn together using the essential features of creativity in education and inquiry-led learning identified in CREATIONS deliverable D2.1.

The deliverable is divided into four sections. **Section 1** describes the design, methodology and data analysis procedures of the online survey. The survey sought perspectives on the relationship between science and creativity, the purpose of science education and the role of creativity within it, the inclusion of creativity and inquiry-learning in teacher education and development programmes and their impact, the affordances and challenges of engaging with creative and inquiry-led pedagogies, and the training educators desired to support them. Respondents were drawn from teachers, scientists, teacher educators, CPD providers and informal science educators.

Section 2 explores the survey findings and draws out the different stakeholders' perceptions about what an effective, creative science educator would need to do, to what purpose, and with what education and training. Section 2.1 analyses the 'scientific creativity' scale developed in the survey, all groups in all countries identified a strong

The CREATIONS project has been funded with support from the European Commission under: H2020-EU.5., H2020-EU.5.a. Project reference: 665917

relationship between science and creativity, and the need to teach to develop this. The exception was with a small group of secondary teachers in England and in Malta, who were much more strongly focused on teaching for scientific knowledge. Question posing and problem solving were identified as key elements in scientific creativity, with developing the ability to ask appropriate questions dominating the top rankings in the purpose of science education. This has important implications for the key professional development aims for educators in teaching for creativity in science. The CREATIONS features of *balance and navigation*, *possibilities,* and *empowerment and agency* are fundamental in negotiating teaching for creativity and scientific knowledge through creative pedagogies. Section 2.2 draws on qualitative survey data and describes the benefits and challenges in using creativities pedagogies of the type proposed for the CREATIONS demonstrators in the context of the CREATIONS features of creative education. Section 2.3 describes educators' perceptions about what makes good educator development in creative science education, drawing on their experiences and perceived needs. Four broad themes were identified: The learner environment and experience, content of provision, quality of provision and peer support and learning community. Of particular interest was the evidence that educators are much more likely to have been trained in IBSE than in teaching for creativity in science, and that professional development in creative pedagogies had had less impact.

In **Section 3**, findings from previous EU projects are synthesised to identify good practice in teacher development programmes in IBSE. Of particular note is the need to develop materials that can be used flexibly in different international contexts and for different purposes. Provision should be affordable, evidence-based, rigorous, concise and accessible, combined with opportunities for practical experience, implementation, reflection and further development. It should have clear opportunities for measurable impact on student

HORIZON 2020

The CREATIONS project has been funded with support from the European Commission under: H2020-EU.5., H2020-EU.5.a. Project reference: 665917

outcomes, with support for how to assess this impact, and enable networking, reflection, and the development of subject and pedagogical content knowledge.

Section 4 summarises the conclusions of the study with respect to considerations and strategies for effective professional development for educators in teaching for scientific creativity and considers the implications of these findings for the different groups of respondents: teachers, scientists, informal science educators and science teacher educators/professional development providers.

Contents

Short Description 1

Introduction 7

1. Survey methodology and design 8

  1.1 The literature base for the survey design 8

  1.2 Survey design 10

  1.3 Data collection 11

  1.4 Data analysis procedures 12

2. Survey Findings 14

  2.1 Effective, creative science education 15

    2.1.1 Relationship between science and creativity 15

    2.1.2 Purpose of science education and the role of creativity 28

  2.2 Creative pedagogies within and beyond the science classroom 31

The CREATIONS project has been funded with support from the European Commission under: H2020-EU.5., H2020-EU.5.a. Project reference: 665917

2.2.1 Benefits and challenges in creative pedagogies 32

2.2.2 Key Implications for creative science pedagogies 42

2.3 What makes good training and professional development for a creative science educator? 45

2.3.1 The learning environment and learner experience 46

2.3.2 Content of provision 46

2.3.3 Quality of provision 51

2.3.4 Peer support and the learning community 51

3. Effective teacher development: lessons from previous research 53

4. Conclusions 59

4.1 Implications for informal science educators 59

4.2 Implications for scientists 60

4.3 Implications for teachers 61

4.4 Implications for teacher educators and the professional development of educators 63

References 65

Appendix 1 67

List of Tables

Table 1: Results of exploratory factor analysis. .... 17~~16~~

The CREATIONS project has been funded with support from the European Commission under: H2020-EU.5., H2020-EU.5.a. Project reference: 665917

Table 2: The Scientific Creativity sub-scale by country. .... 18~~17~~
Table 3: The Scientific Creativity sub-scale by role. 19
Table 4: Items included in 'Scientific Creativity' scale .... 21~~20~~
Table 5: Items not included in 'Scientific Creativity' scale 21
Table 6: Percentage of responses ranking 'Purpose of Science Education' statements 30
Table 7: Benefits and Challenges in Creative Pedagogies 41
Table 8: Engagement with creative science education activities 42
Table 9: IBSE and Creativity Training – Primary Teachers 48
Table 10: IBSE and Creativity Training – Secondary Teachers 48
Table 11: Impact of IBSE and Creativity Training – Primary Teachers 49
Table 12: Impact of IBSE and Creativity Training – Secondary Teachers 49
Table 13: Synthesis of modules in IBSE training programmes 58

List of Figures

Figure 1: Malta .... 18~~20~~
Figure 2: United Kingdom .... 18~~20~~
Figure 3: Good Practice in Demonstrator Development .... 44~~48~~

Acknowledgements: The CREATIONS UK team would like to thank all the survey participants for engaging with the survey. The Association for Science Education in the UK have been very helpful in allowing us to lead one of the 'twitter chats' to disseminate the project and seek wider participation. Thanks also to project colleagues for their efforts in refining and disseminating the survey.

HORIZON 2020

The CREATIONS project has been funded with support from the European Commission under: H2020-EU.5., H2020-EU.5.a. Project reference: 665917

Introduction

This deliverable presents the results of a survey designed to explore the perspectives of different stakeholders on the relationship between creativity and science in science education. Implications for training and professional development for educators in creativity and science were explored, alongside educators' perspectives on the affordances and challenges of the kinds of activities constituting the proposed CREATIONS demonstrators. Conclusions regarding effective teacher development in IBSE and Teaching for Creativity in Science from previous research projects in Europe were synthesised and combined with the survey findings to offer insight into effective teacher development for creativity in science education. These findings will inform the design and implementation of the CREATIONS demonstrators. Throughout the deliverable, connections have been made wherever possible to the CREATIONS features as outlined in D2.1; these connections are italicised and coloured in blue to highlight them.

The CREATIONS project has been funded with support from the European Commission under: H2020-EU.5., H2020-EU.5.a. Project reference: 665917

1. Survey methodology and design

1.1 The literature base for the survey design

Current research, policy and practice in creativity, science and education across Europe were used to inform the design of the survey. The literature review reported in the CREATIONS project deliverable D2.1 considered the purposes of science education with reference to creativity and highlighted the positive relationship apparent in the literature between Inquiry-based Science Education (IBSE) and creativity, between the use of digital technologies and creativity, and in access to 'real scientists and real data' to engage young people with science. Of particular note with respect to the survey design was the point that 'teaching for creativity in science requires skills-based approaches that include contextualised, inquiry-based pedagogies...that are often open-ended, student-oriented, exploratory and group-based'. Such pedagogies have been identified as potentially challenging for teachers working in time-pressed curriculum contexts, with limited resources. A further point highlighted in this literature was the debate within the field around the role of knowledge in inquiry-based science education and the level of guidance students might require in order to be able to, for example, 'generate scientifically relevant questions' (a key aspect of IBSE highlighted in the PATHWAYS project[1]).

To explore different stakeholders' perspectives in relation to these key elements, the survey was designed to address the following questions:

[1] See the PATHWAYS project website, http://pathway.ea.gr, for resources and publications.

HORIZON 2020

The CREATIONS project has been funded with support from the European Commission under: H2020-EU.5., H2020-EU.5.a. Project reference: 665917

1. What are the perspectives of different stakeholder groups (primary teachers, secondary teachers, informal science educators, teacher educators and scientists) about the relationship between science and creativity?
    a. What are the implications of these perspectives for the implementation of creative science pedagogies?
    b. What are the implications of these perspectives for teacher education in creative science pedagogies?
2. What are the perspectives of different stakeholder groups about the purposes of science education?
    a. What are the implications of these perspectives for the implementation of creative science pedagogies?
    b. What are the implications of these perspectives for teacher education in creative science pedagogies?
3. What is already included in teacher education courses in supporting teachers in teaching IBSE and teaching for creativity in science?
4. What training have teachers received in teaching IBSE and teaching for creativity in science? What training has had the highest impact on them?
5. What do teachers believe are the features of good teacher training and professional development?
6. What do teachers believe are the affordances and challenges of engaging with creative science pedagogies, through collaborative activities in real and virtual contexts within and beyond the science classroom? Thus, what teacher development is required to support them in using these approaches?

HORIZON 2020
The CREATIONS project has been funded with support from the European Commission under: H2020-EU.5., H2020-EU.5.a. Project reference: 665917

1.2 Survey design

In order to identify the profile of the effective creative science educator and the nature of effective professional development in this area, we sought the views of people with varying types of experience of and interaction with creative science teaching. A semi-structured survey in the form of an electronic questionnaire was selected as it could be distributed to, and self-administered by, a wide range of international participants in a short time frame. The LimeSurvey™ tool was used for questionnaire design, online hosting of the questionnaire, and data capture.

For purposes of data triangulation, illumination of themes and statistical data analysis, the survey included a variety of question types. These included:

- Likert-type rating scales
- Ranking statements in order of importance
- Open questions

To develop descriptions of frequency of mentions and to obtain accurate comparisons between stakeholder groups, quantitative questions were asked. The open-endedness of qualitative approaches allowed themes to emerge that may not have been anticipated in advance of the survey.

The questionnaire was in 3 sections. The first two sections (Background Information and Beliefs about Creativity in Science Education) asked the same questions of all respondents. The next section used a branching structure to enable general teachers, informal science

HORIZON 2020
The CREATIONS project has been funded with support from the European Commission under: H2020-EU.5., H2020-EU.5.a. Project reference: 665917

educators and those working in teacher development to respond to specifically tailored questions.

1.3 Data collection

Opportunistic and snowball sampling was used; the LimeSurvey™ questionnaire link was passed via email to each consortium member, who forwarded it electronically to:

- Primary and secondary teachers
- Science educators in the informal education sector
- Scientists
- Teacher trainers
- Other relevant individuals – artists, public engagement with science specialists etc.

Consortium members were asked to forward the survey to at least ten contacts who they felt would likely to complete it, using their personal networks; this approach was taken to try and ensure at least some responses from each of the partner countries. Targeted circulation of the survey in the UK was also utilised; it was circulated to the Royal Society of Biology, Royal Society of Chemistry, Institute of Physics, Association for Science Education and the ASTE and further distributed by these organisations to their mailing lists where appropriate. Social media was also used to widen the circulation; the link was posted to the Times Educational Supplement Science forum page and the Science Educators in Europe Facebook page. The survey was also sent to the PSCI-COM (public engagement in science) listserv (an email distribution list for all those working in the field of public engagement with science), and sent to the workshop participants and database of contacts from the CREAT-IT project.

HORIZON 2020

The CREATIONS project has been funded with support from the European Commission under: H2020-EU.5., H2020-EU.5.a. Project reference: 665917

The questionnaire was completed anonymously with a final question inviting respondents to give their email address if they were interested in further involvement in the project. Ethical approval was sought in line with the University of Exeter College of Social Science and International Studies policy and the policies and procedures of the EU H2020 with respect to data collection, reporting and access. In the reporting of the survey no respondent is identified. The survey was live from 1st – 29th February 2016.

In addition to the data generated by the online survey, further triangulation has been provided by referring to data gathered from an online Twitter debate hosted by the Association for Science Educators (ASE) and led by one of the project researchers. The debate, entitled 'Creativity in Science Education' ran for one hour on the evening of 15th February, 2016. It was publicised by the ASE to its members and formed part of their regular series of weekly Twitter debates. The resulting text was copied from Twitter and ordered chronologically and by thread of conversation before being analysed using the same thematic coding as the survey data.

1.4 Data analysis procedures

The on-line LimeSurvey™ tool was used to collate and store the data. Qualitative and quantitative responses were separated for ease of analysis.

The quantitative data underwent descriptive numeric analysis and comparisons; the data from the Excel™ spreadsheet was exported to SPSS™ which was used to calculate mean ratings, standard deviation, modal values and frequencies.

The CREATIONS project has been funded with support from the European Commission under: H2020-EU.5., H2020-EU.5.a. Project reference: 665917

For the qualitative analysis, responses were transferred to separate documents according to the question number, and then analysed thematically using MaxQDA™. Initial codes were developed deductively by using constant comparison; responses to each question were considered separately first, before identifying cross-themes. The codes were then re-grouped into categories according to the CREATIONS features (excluding the data on professional development and teacher training, which was considered separately). Due to the uneven nature of the sample size, it was difficult to consider responses according to the country of origin of the respondent; the sample has therefore been considered as a whole for the purposes of the qualitative data analysis, although the role (e.g. secondary school teacher) of respondents has been considered where appropriate. In coding the data, responses to the open-ended questions that were considered to be inconsistent (e.g. responding to a different question in error) were not included.

The CREATIONS project has been funded with support from the European Commission under: H2020-EU.5., H2020-EU.5.a. Project reference: 665917

2. Survey Findings

Following cleaning of the data, 209 partially completed questionnaires were received with sufficient responses to include in the analysis. 195 questionnaires had complete responses. The largest number of responses came from England (27%) with 'Other' (including the USA, Canada, Scotland and Australia) making up the next largest group (22.9%). Scotland and England were considered separately as Scotland's education system has been devolved from central UK government. The high number of non-European survey respondents reflects the fact that the survey was distributed to email lists which have an international membership (including a large proportion of North American members), and also the decision to circulate the survey less widely amongst partner countries.

Overall, the majority of respondents had some experience and background in education: 67% hold a teaching qualification. The largest group of respondents were teacher educators (24%), followed by Secondary science teachers (21%). 16% of respondents were Scientists. A large proportion (73%) of the teacher educators responding to the survey were from non-EU countries; from within the EU, 25% of the sample were Secondary science teachers, 20% were Scientists, 18% were informal science educators, 11% were primary teachers, and 8% were teacher educators. The 'other' category comprised 16% of the sample and included science communicators, outreach educators and various higher education roles linked to science.

Respondents covered a breadth of experience within their respective roles, although the majority (65%) of science educators in informal settings has been in their roles for 5 years or less. 59% of respondents were female and 40% male: 2 respondents chose not to give their gender.

HORIZON 2020

The CREATIONS project has been funded with support from the European Commission under: H2020-EU.5., H2020-EU.5.a. Project reference: 665917

2.1 Effective, creative science education

In order to understand the profile of an effective, creative science educator, it was necessary to understand the perceptions of teachers, teacher educators, scientists and informal science educators about what an effective, creative science educator would need to do, and to what purpose. A series of questions were therefore asked in order to elicit information about the relationship between science and creativity, the purpose of science education, and the role of creativity in science education.

2.1.1 Relationship between science and creativity

Respondents were asked 'Do you think there is a relationship between science and creativity?'. All Primary teachers and Informal Science Educators who responded agreed with this statement, 93% of Secondary Science teachers agreed, and 5% disagreed.

In order to explore the different perceptions of the relationship between science and creativity across the range of roles, a series of statements were posed to respondents, asking them their level of agreement on a 5 point Likert scale. These statements were based on the educational research literature discussing science and creativity, and included statements about the general relationship between the two, the relationship in an educational context, and possible barriers.

Factor Analysis: A 'Scientific Creativity' Scale

The CREATIONS project has been funded with support from the European Commission under: H2020-EU.5., H2020-EU.5.a. Project reference: 665917

To simplify the initial analysis by role and country, we conducted a factor analysis of the statements on the topic of science and creativity to identify possible scales. Though the relatively small sample size is potentially problematic in conducting such an analysis, exploratory factor analysis enabled us to identify a reliable scale. Appendix 1 details the statistical analysis processes that were undertaken in order to generate the 'Scientific Creativity' scale. Items not held within this scale were labelled 'disciplinary science' but were treated separately in the analysis.

Scientific Creativity	Disciplinary Science
Science requires you to use your imagination	Scientific inquiry is about using scientific method
There is a place for creativity in scientific method	Young people need prior knowledge to ask appropriate questions
Science should encourage young people to ask questions about the world around them	
Scientific inquiry is a creative endeavour	
Scientific inquiry is about critical questioning	
Science education should help children generate outcomes that are original to them	
Creativity in Science is collaborative	

HORIZON 2020
The CREATIONS project has been funded with support from the European Commission under: H2020-EU.5., H2020-EU.5.a. Project reference: 665917

Table 1: Results of exploratory factor analysis.

The sub-scale 'Scientific Creativity' was explored by generating a single mean score for the scale for each respondent. Descriptive statistics were then used to analyse this scale by country and by role.

Exploring 'Scientific Creativity' by country

Respondents from all countries were generally positive to strongly positive about the relationship between science and creativity, although it is worth noting that there may be an element of sampling bias in that the respondents who chose to complete the survey may be likely to be those interested in science and creativity. Countries with the lowest mean values and largest standard deviation were Malta and England (see table X).

Country	Mean	Std. Deviation
England	4.09	0.678
Other (mainly N. America)	4.40	0.765
Germany	4.24	0.421
Greece	4.49	0.301
France	4.48	0.459
Malta	4.01	1.106
Norway	4.55	0.334
Serbia	4.32	0.514
Spain	4.37	0.458

1=strongly negative to 5= strongly positive responses to the combined statements relating science and creativity.

HORIZON 2020

The CREATIONS project has been funded with support from the European Commission under: H2020-EU.5., H2020-EU.5.a. Project reference: 665917

Table 2: The Scientific Creativity sub-scale by country.

For these two countries, more detailed inspection of the findings indicates a small number of respondents who strongly disagreed with the combined statements relating science and creativity (Figures 1 and 2)

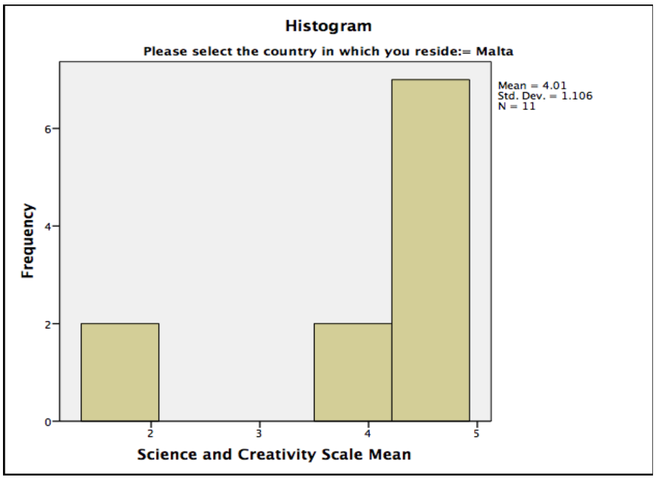

Figure 1: Malta

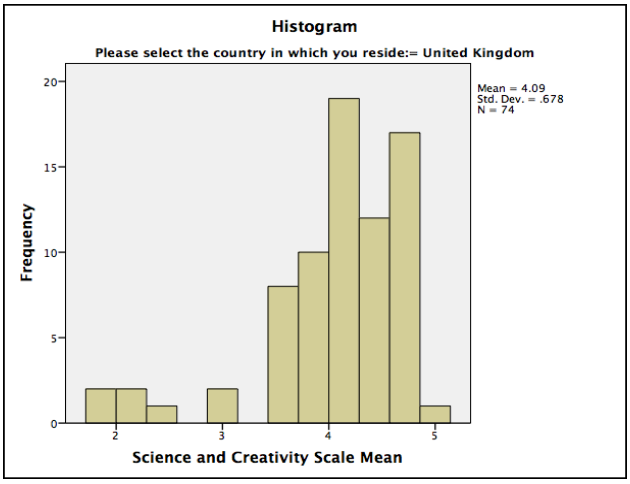

Figure 2: United Kingdom

Given the overall strong agreement in the findings across different countries, it was taken as reasonable to analyse the whole data set by role, rather than by role and country, particularly given that a previous study, 'CREAT-IT', conducted a detailed analysis of science teachers' perceptions of creativity and science across different EU countries, many of whom are also involved in this project.

Exploring 'Scientific Creativity' by role

Once again, the results show broad agreement across the sample, indicating strong agreement about the relationship between science and creativity. Of particular note is that

The CREATIONS project has been funded with support from the European Commission under: H2020-EU.5., H2020-EU.5.a. Project reference: 665917

both scientists and educators have similar strong agreement. In terms of the range of responses, results indicate that at least one respondent from the groups secondary science teachers, teacher educators and scientists showed some level of disagreement.

Role	Mean	Standard Deviation	Minimum	Maximum
Primary Teacher (Age 4-11)	4.4	0.8	4	5
Secondary Teacher (11-18)	3.9	0.1	2	5
Teacher Educator	4.4	0.8	1	5
Informal Science Educator	4.4	0.1	4	5
Scientist	4.3	0.1	2	5

1=strongly negative to 5= strongly positive responses to the combined statements relating science and creativity.

Table 3: The Scientific Creativity sub-scale by role.

Exploring the variability in responses by role, it is interesting to note that all Primary teachers and Science Educators in informal settings had mean scores for the scientific creativity scale of 4 to 5, compared with Secondary teachers, where 16.3% had mean scores <3. Just 1 teacher educator and 1 scientist responded with a mean score of 1 on the combined scale. **This suggests that there is a small group, particularly amongst**

The CREATIONS project has been funded with support from the European Commission under: H2020-EU.5., H2020-EU.5.a. Project reference: 665917

secondary science teachers, who are unconvinced about the relationship between science and creativity. This has implications for this project with respect to teacher professional development and the design of the CREATIONS demonstrators. This suggests a potentially interesting line of future research.

In order to understand the contrasting perspectives of these secondary science teachers in more depth, an analysis of individual scale items was conducted, and triangulated (defined here to mean compared with and substantiated by) with the teachers' responses to the open-ended questions in the survey.

Item included within 'Scientific Creativity' scale	Mean	Std. Dev	Minimum	Maximum
Scientific Inquiry is a creative endeavour	3.8	1.3	1	5
Science should help children generate outcomes that are original to them	3.78	1.1	1	5
Science should encourage young people to ask their own questions about the world around them	4.1	1.3	1	5
Science requires you to use your imagination	4.1	1.3	1	5
Creativity in Science is collaborative	3.5	1.1	1	5
There is a place for creativity in scientific method	4.1	1.1	1	5
Scientific Inquiry is about critical questioning	3.9	0.9	2	5

HORIZON 2020

The CREATIONS project has been funded with support from the European Commission under: H2020-EU.5., H2020-EU.5.a. Project reference: 665917

Table 4: Items included in 'Scientific Creativity' scale

Items not included in 'Scientific Creativity' scale	Mean	Std. Dev	Minimum	Maximum
You cannot expect young people to ask appropriate questions without some prior knowledge about science	2.8	1.3	1	5
Scientific Inquiry is about using scientific method	3.6	1.1	2	5
Creativity in Science is Individual	3.1	1.1	1	5

Table 5: Items not included in 'Scientific Creativity' scale

Examination of individual cases demonstrated that where teachers agreed with the statements included in the scale, they tended to agree with across the board. More contentious was the statement, 'You cannot expect young people to ask appropriate questions without some prior scientific knowledge'. With respect to this statement, there is a small but statistically significant negative correlation with the overall 'scientific creativity' sub-scale, suggesting that many teachers who agreed with the combined statements relating science to creativity disagreed that prior knowledge was necessary for pupils to generate their own appropriate questions (Pearson correlation = -0.306, $p<0.05$). **Teachers who tended to disagree with the statements making up the 'scientific creativity' sub-scale tended to agree with this statement, suggesting they valued the role of knowledge in science.** However, some teachers who broadly agreed

The CREATIONS project has been funded with support from the European Commission under: H2020-EU.5., H2020-EU.5.a. Project reference: 665917

with the statements in the 'scientific creativity sub-scale' also agreed with this statement, suggesting some disagreement over the need for prior knowledge in pupils' question generation. It is worth noting that this debate regarding the relative value of knowledge and creativity is not exclusive to science; it occurs in the arts as well. The qualitative data we collected via the survey supports our interpretation of this range in points of view. One teacher stated that:

> *"I have an Engineering PhD and am published, therefore I have designed experiments and thought through ideas that have never been considered before. If that is not creativity I do not know what is. However...I think that much of the getting children to 'behave like scientists' is silly - you can only do that once you have the underlying knowledge."* Secondary Science Teacher

This is interesting both in relation to the design of the CREATIONS demonstrators and also because it relates closely to a discussion within the literature about the balance between unguided and more structured approaches to inquiry and creativity within science lessons (see D2.1), and to the findings from cognitive science that knowledge is important in order to be able to 'think like a scientist', including problem-solving and other aspects that fall under a 'scientific creativity' umbrella.

In terms of an effective, creative science educator therefore, it would appear that the CREATIONS creativity feature 'balance and navigation' is crucial in supporting secondary science teachers in particular to negotiate the interaction between knowledge and creativity within the secondary curriculum.

HORIZON 2020

The CREATIONS project has been funded with support from the European Commission under: H2020-EU.5., H2020-EU.5.a. Project reference: 665917

Apart from general agreement that prior knowledge is required in order for pupils to ask appropriate questions, the secondary teachers who broadly disagreed with statements relating to science and creativity did not tend to represent a general pattern of response. Their comments and profiles do all suggest that they believe there is some aspect of creativity to science, but that it is problematic to relate this to secondary education for various reasons. For example, one teacher, who suggested that *'there are some students who are creative but struggle to understand abstract concepts e.g atomic structure as it is hard to imagine'* agreed that there was a role for creativity in scientific method and felt that science was individual, but disagreed with all the other statements, suggesting that they did not feel that features of creativity such as dialogue, collaboration and questioning had a role in science. A different teacher, who also tended to disagree with the science and creativity statements, noted *that '...in some respects yes [there is a relationship between science and creativity] for example when asking pupils to hypothesise about why something happens or how something works. In other respects they need to learn accepted methods or information (for example for an exam) which may be far more time consuming (when time constraints are an issue) if pupils go off on a tangent and think too creatively.'* Yet another teacher agreed that science education should help young people achieve outcomes that are original to them but was neutral or disagreed with all the other statements. This teacher commented that *'without curiosity there can be no creativity'* which perhaps suggests an interpretation of the statements rooted in the need to stimulate young people's curiosity before any creativity in science is possible.

Following thematic analysis of the qualitative data relating to this question, the following themes emerged:

The CREATIONS project has been funded with support from the European Commission under: H2020-EU.5., H2020-EU.5.a. Project reference: 665917

- The intrinsically creative nature of scientific inquiry
- The nature of creativity
- The relationship between creativity and knowledge

The intrinsically creative nature of scientific inquiry

This was the most commonly found theme in the data, with respondents across all groups referring to it in different ways. One perspective was a fairly straightforward view that it is impossible to separate creativity from scientific inquiry – *'Both are interrelated and without creativity there would not be scientific inquiry in the first place'* (secondary science trainee teacher), *'I think scientific inquiry is by its nature creative'* (informal science educator). Others related creativity more specifically to the process of scientific inquiry; respondents referred both to how creativity provides the initial spark for an investigation to occur, and how it is important at each stage of the process. Reference was made for the need for creativity in planning experiments, hypothesis development and testing, observations, and interpretation of results.

The most commonly cited aspect of the inquiry process requiring creativity was that of question posing – *'Individuals create questions and suggest answers and ways to find answers: there's no way this can just follow prescribed routes!'* (secondary teacher), *'Posing appropriate questions is a creative act.'* (secondary science trainee teacher).

This links strongly to the CREATIONS features in terms of both dialogue and possibilities; it is clear that educators see the potential for questions as a site of creativity and this is worth emphasising in the development of future teachers.

The CREATIONS project has been funded with support from the European Commission under: H2020-EU.5., H2020-EU.5.a. Project reference: 665917

Another frequently occurring theme was that of problem solving, both in terms of the nature of scientific inquiry itself and regarding the creative application of scientific method - *'The strict scientific method isn't especially creative, but solving problems to apply it can be'* (informal science educator).

This potential for creativity within investigation design is something that is worth highlighting in teacher development and training programmes; it links to the possibilities discussed within the CREATIONS features.

It is interesting to note some differences according to role in this area; secondary teachers were the most likely to refer to specific aspects of the inquiry process (hypothesis testing and question posing in particular), whereas informal science educators were the largest group to refer to the impossibility of separating scientific inquiry and creativity in a more general sense. Primary teachers appeared to have a more holistic view of both creativity and learning

> *'In order for scientific inquiry to take place in an infant classroom, the children need to be able to 'experience' scientific enquiry. This is usually undertaken in a creative manner'* (Primary school teacher).

The relationship between creativity and scientific method was discussed, with some taking the view that the method itself is rigorous, with some space for creativity within it, whereas others stated that there is no strict formula for scientific inquiry.

> *'"Scientific Method" is not a rigid formula or system, more a broad approach that allows for a wide variety of creative practices. The most rigid definitions of*

HORIZON 2020

The CREATIONS project has been funded with support from the European Commission under: H2020-EU.5., H2020-EU.5.a. Project reference: 665917

*"Scientific Method" tend to accurately describe *some* physics, but exclude many branches of science that work in related but different ways.'* Primary school trainee teacher

This potential tension in viewing the relationship between the rigour of scientific inquiry and the potential for creativity within it, particularly between different branches of the sciences, is perhaps troubling and certainly something that should not be ignored in teacher training and development where trainees may come from a range of scientific disciplines. Future research may address this by seeking more detailed data from those with backgrounds in different scientific disciplines.

The nature of creativity

Responses to this question illustrated various perspectives. The most commonly cited aspect was the possibility of thinking differently or 'thinking outside the box' (this particular phrase occurred eight times, from respondents across all groups). The capacity to 'think differently' was seen to have various applications and to be necessary at different stages of the investigation process;

'Creativity is the core of a successful enquiry. Unless there is some outside the box thinking whether in the development of the nature of the enquiry, the key questions to be investigated or the interpretation of the results then science simply becomes a reiteration of previous theories.' Secondary teacher

Divergent thinking was seen to support question posing, finding new solutions to problems, and developing innovative methods.

HORIZON 2020

The CREATIONS project has been funded with support from the European Commission under: H2020-EU.5., H2020-EU.5.a. Project reference: 665917

A broader connection between innovation and creativity was apparent, with several respondents making reference to the development of new ideas as being where creativity may be connected to scientific inquiry. A link was also seen between creativity and imagination, with some respondents considering that taking new approaches to question posing or problem solving required imagination to visualise possible results or outcome. Finally, creativity was seen as making connections between ideas.

Relationship between creativity and knowledge

This was perhaps the most contentious aspect of this data. In a minority of cases (all UK secondary teachers), a distinct tension between creativity and knowledge was identified. Creativity was described in one case as actively distracting from acquiring the factual and method knowledge needed to pass exams. The notion that is possible to 'think too creatively' is concerning, especially in the light of the above data regarding the intrinsically creative nature of science. It is interesting to note that this view was also expressed by a UK teacher educator in response to the question regarding content of teacher education programmes:

> *Understanding where creativity can be important (developing theories) and where creativity has to be subservient to understanding current thinking and detailed knowledge.*

An alternative perspective on the relationship between creativity and knowledge was offered in terms of the potential of creativity to support autonomy and ownership over learning; notably this was referred to only once by a secondary teacher, whereas a third of the primary school teacher respondents made reference to this aspect:

HORIZON 2020
The CREATIONS project has been funded with support from the European Commission under: H2020-EU.5., H2020-EU.5.a. Project reference: 665917

Allowing children to develop their creativity in science encourages them to explore concepts, discover for themselves and, in turn, develop key scientific skills.

The final perspective in this area was that creativity might arise from the application of new knowledge gained from an investigation process.

Key Findings

- A strong relationship between creativity and science was generally acknowledged, with the exception of a small group amongst secondary science teachers, who were less convinced.
- The relationship between knowledge and creativity is perceived in different ways and is an important consideration in teacher training and development – the CREATIONS feature of Balance and Navigation is crucial
- Question posing and problem solving were the most commonly cited areas of creativity
- Secondary teachers focussed more on aspects of the scientific method when discussing creativity than other groups
- 'Thinking outside the box' is seen as an important element of creativity

2.1.2 Purpose of science education and the role of creativity

To explore perceptions about the purpose of science education, respondents were asked to place a series of statements about the purpose of science education, drawn from the literature review undertaken in D2.1 and broader literature about the nature of science and purpose of science education. The table below shows each item and the percentage of

HORIZON 2020

The CREATIONS project has been funded with support from the European Commission under: H2020-EU.5., H2020-EU.5.a. Project reference: 665917

respondents placing it at any given rank. It can be seen that ''stimulating young people's interest in science' and 'being able to ask appropriate questions about the world around them' are the two items most likely to be ranked highly, with general agreement that preparation for a career in science was relatively low priority. Acquiring accepted scientific knowledge had two peaks, at rank 3 and rank 7, indicating variability in respondents' perception of its importance in the purpose of science education, which bears out the analysis in the previous section highlighting disagreement over the relative importance of prior knowledge in enabling students to ask questions (a key facet of creativity), and the broader relationship between creativity and knowledge. Other items showed a more even spread suggesting a range of opinion. However, the table shows that 'Understanding scientific method', 'developing science practical skills' and 'being able to interpret science in the media' were all most commonly ranked relatively low, whereas 'being able to apply science to real-world problems' was ranked relatively high. From this, we can draw a broad conclusion that overall, respondents to this survey felt that the most important purposes of science education were to stimulate enjoyment of the subject, develop their curiosity and support them applying knowledge and understanding of science.

Understanding the nature, knowledge base and skills of science were generally deemed relatively lower in importance, although it must be acknowledged that this in no way means respondents felt they were not important goals.

HORIZON 2020
The CREATIONS project has been funded with support from the European Commission under: H2020-EU.5., H2020-EU.5.a. Project reference: 665917

	Ranking of statement (1= most important purpose)								
Purpose of Science Education Statement	1	2	3	4	5	6	7	8	9
Acquiring accepted science knowledge	3.8	5.7	12.0	9.1	11.5	15.3	15.8	10.5	11.0
Understanding the nature of science	15.8	11.5	13.9	9.6	17.2	8.1	8.6	7.2	2.9
Understanding scientific method	4.3	6.2	10.0	12.4	11.5	12.9	17.7	11.5	8.1
Stimulating young people's enjoyment of science	30.8	15.8	12.9	13.9	8.1	3.3	3.3	3.8	2.9
Being able to ask appropriate questions about the world around them	23.9	30.6	12.0	8.6	6.7	4.3	4.3	1.0	2.4
Preparation for a career science	0.5	1.0	0.5	3.8	2.4	7.7	8.6	24.9	44.5
Developing science practical skills	1.4	2.4	6.2	12.9	11.0	19.1	14.4	17.7	9.1
Being able to interpret science in the media	1.9	6.7	8.1	11.5	11.5	12.4	14.8	15.3	11.5
Being able to apply science to real-world problems	12.4	14.8	19.1	12.9	14.8	11.0	6.2	1.9	1.4

Table 6: Percentage of responses ranking 'Purpose of Science Education' statements.

The CREATIONS project has been funded with support from the European Commission under: H2020-EU.5., H2020-EU.5.a. Project reference: 665917

The relative importance placed on questioning as a key purpose of science education is interesting from the perspective of the development of effective, creative science pedagogy and pedagogues. It could be argued that many of the other purposes included in this list might be subsidiary to this overall purpose in enabling young people to both ask and then answer questions about the world around them, which is indeed the essence of science and is also one of the ways in which science is most clearly linked to creativity by many respondents, as described above.

Key findings

- Respondents felt that the most important purposes of science education were to stimulate enjoyment of the subject, develop their curiosity and support them applying knowledge and understanding of science.
- Enabling question posing is an overarching principle in science education

2.2 Creative pedagogies within and beyond the science classroom

The survey provided much useful information about the perceptions of activities which could contribute to creative science pedagogies both within and outside the classroom. Questions were posed about the benefits and challenges of five categories: activities that integrate science and the arts, use of digital games, access to real scientific data, access to real scientists via real or virtual visits, and 'other'. Responses were analysed thematically and then grouped according to the CREATIONS features.

The CREATIONS project has been funded with support from the European Commission under: H2020-EU.5., H2020-EU.5.a. Project reference: 665917

2.2.1 Benefits and challenges in creative pedagogies

Dialogue

This feature was evident mainly with regard to opportunities for dialogue between scientists and learners, and for connections to be made between science teaching and learning and the 'real world' of science by linking theory and practice.

Dialogue between scientists and learners

Respondents identified the opportunities for actual dialogue, in terms of communication with scientists, presented by visits to labs. They considered that this also allowed for demystification of scientists (and science itself), and an increased understanding of the role of scientists and their identity, with the potential to address stereotypes. Potential challenges to such dialogue were considered to be the ability of scientists to communicate their work at an appropriate level, and a willingness to engage with educational projects on the part of relevant organisations or individuals. Data from the Twitter debate also highlighted the possibility of dialogue with important living or historical scientists, through real communication or teaching activities focused around their life stories; this was perceived to be a means of highlighting the significance of originality and creativity in science. This feature also encompasses the 'dialogic' nature of creativity, which is less actively acknowledged within survey responses.

Linking theory and practice

The CREATIONS project has been funded with support from the European Commission under: H2020-EU.5., H2020-EU.5.a. Project reference: 665917

This was a commonly identified benefit of visits to real labs. Respondents felt that 'bringing science to life' could help learners to see the value of their existing knowledge, and to make connections between what they know and 'real science'.

Interdisciplinarity

The type of activity where interdisciplinarity was referred to most often was that combining the arts and sciences. Respondents considered that the holistic nature of these projects could benefit learners, and that such an approach mirrored the way the brain makes links between different areas. They also stated that learners were enabled to draw on and develop skills from other disciplines. One primary school teacher respondent stated that 'teaching through art can create a strong relationship between scientific inquiry and creativity', showing therefore that this skill transfer can be a two-way process. The potential for transferable skill development was also identified with relation to the use of digital games and access to real data, both of which were perceived to develop ICT (Information and Communication Technology) and/or mathematical skills. Reference was also made to the development of broader transferable skills such as team work and critical thinking skills (digital games), and problem solving, confidence and public speaking (arts and science projects).

Respondents did identify several challenges presented by interdisciplinarity, most notably with regard to perceived or existing differences in the cultures of arts and sciences, both in terms of approaches to creativity and more generally. The Twitter debate generated some interesting responses in this area, with one participant raising the question of 'a difference between creative 'solutions' drawing on knowledge [in the sciences] and creative 'expression' drawing on emotions [in the arts]?, and another wondering whether 'from a

HORIZON 2020

The CREATIONS project has been funded with support from the European Commission under: H2020-EU.5., H2020-EU.5.a. Project reference: 665917

pupil point of view [it is] 'safer' to be creative in arts where it is expected?'. Another strand in this debate (in which the participants were all science educators of some form) was a strongly felt divide between the arts and the sciences: 'this sounds a complex area for what is very left side of brain subject.' 'You have don't have to engage with 'creatives' like Art & design to nurture creativity in science'. This was echoed in the survey data, where reference was made to 'distracting' pupils from science by 'art' (interestingly, by a science educator in the informal sector). A more specific aspect of this divide appears to the different specific vocabulary used by the arts and science, referred to as the 'different technical languages spoken' and the need for 'immersion in the lexicon'. This issue was referred to elsewhere in the survey by a teacher educator, who cited the need for

> *'A thorough understanding of the nature, and disciplinary literacies, of both the scientific and creative domains included in the teaching. E.g. using music in science teaching requires that the teacher needs to have thorough knowledge of both the nature of science and nature of music. This can possibly be achieved with one person having both competencies, or through close collaboration between two teachers. The latter will, however, most likely be quite demanding in terms of resources and time, but might nevertheless be very valuable'*

The CREATIONS feature acknowledges that disciplinarity must remain strong within interdisciplinarity, and suggestions such as the above might help to reinforce that strength. The final challenge related to interdisciplinarity identified was that of making genuine links between the arts and sciences, which may appear *'very superficial and bolted-on rather than properly integrated'* (again, interestingly this statement came from a science educator in the informal sector).

The CREATIONS project has been funded with support from the European Commission under: H2020-EU.5., H2020-EU.5.a. Project reference: 665917

Individual, collaborative and communal activities for change

This feature was applied to the data in the areas of inclusion and access, opportunities for communication and collaboration, the opening up of alternative contexts for science, and the potential for new perspectives.

Inclusion and access

Reference was made to inclusion across several activities. Visits to labs were considered to have value in this area – *'Good aspirations, anyone can do it – equality' 'removes the 'I can't do it' element.'* (both observations from secondary teachers). Arts and science activities were also considered to be accessible and to allow students to *'see areas they are able to succeed in'.* They were also seen to offer good opportunities to address a range of learning styles, for example kinaesthetic and visual. Digital games were perceived to be widely available and to provide *'immediate access for some pupils (doesn't apply to all)'*. This last statement points to an issue identified elsewhere regarding inclusion; not all activities were considered to be inclusive. Visits to labs presented challenges in terms of meeting the interests and needs of all pupils. They were also perceived as potentially difficult in terms of gaining access to scientists or labs, and the group size that could be accommodated in such venues. Access to data was in one case referred to as only appropriate for the oldest pupils in secondary school. Data was also perceived as inaccessible in terms of the complexity of interpretation and understanding, and the additional skills required to make sense of it; this was the biggest challenge perceived to be presented by the use of real data.

Opportunities for communication and collaboration

HORIZON 2020

The CREATIONS project has been funded with support from the European Commission under: H2020-EU.5., H2020-EU.5.a. Project reference: 665917

Arts and science activities were perceived to offer opportunities to communicate in a different way about science, by providing different ways of approaching and interpreting science information. They were also seen as *'enjoyable to be a part of'*, suggesting a possibility of group identity and collaboration. Digital games also offer a social aspect, and *'opportunities to meet that don't exist in the physical world'* (science educator in the informal sector).

Alternative contexts for science

Digital games were seen to present opportunities beyond the physical world by stimulating real world scenarios or future effects. They were also perceived to show that science is *'not necessarily lab based'*. However, this view was not universal, with one secondary science trainee teacher stating that *'the medium becomes more important than the reality and the learning may not transfer to real world'.*

New perspectives

Arts and science activities held the most potential here; they were seen to offer new horizons and a different perspective for learners, and to give teachers the opportunity to *'see students in a different light'* (secondary school teacher).

Balance and navigation

This feature offered the most data, reflecting as it does the fundamental role of educators in science education of balancing control and freedom, prior knowledge and new knowledge, structure and openness. Encompassed within this feature is also one of the greatest challenges educators currently face, to which many respondents made reference;

HORIZON 2020
The CREATIONS project has been funded with support from the European Commission under: H2020-EU.5., H2020-EU.5.a. Project reference: 665917

the pressures, tensions and dilemmas of assessment, time pressures and performativity in general. Time and money were cited as the biggest barriers to participation or initiation across the spectrum of activities, alongside practical organisation issues of collaborating with appropriate partners, geographical factors, and technical requirements/resources.

Another significant issue that was identified was the challenge of identifying or maintaining a focus on scientific learning. This was seen as a particularly significant issue in projects involving arts and sciences, with three respondents referring to the potential of science 'getting lost' in these activities. This was also seen as an issue in terms of digital games, in terms of the students' focus – 'sometimes the game could be more important for students than the content and the knowledge' and in finding games that had the right scientific content or fitted with other learning objectives. Balancing prior and new knowledge also arose as an issue, both in the context of arts and science activities and access to real scientists and labs; some respondents felt that in both contexts students needed prior knowledge first.

A positive view of the potential to model and generate creativity through arts and science activities was offered, reflecting the aspect of this feature that concerns creative practice on the part of those leading educational activities. The Twitter debate also provided interesting data in this area, with participants discussing the difference between teaching creatively, enabling creativity and teaching creativity. One person also raised the issue of measuring creativity – *'I think the problem is that creativity needs defining so it can be measured. Sad but elephant in the room'.* However, this is countered by the findings of D2.1, which illustrates that many researchers argue that creativity cannot be measured but should be approached in terms of documentation and characterisation.

HORIZON 2020

The CREATIONS project has been funded with support from the European Commission under: H2020-EU.5., H2020-EU.5.a. Project reference: 665917

A final theme in this area was that of expertise on the part of activity leaders; this was raised as an issue regarding arts and science activities, where it was felt that leaders did not always have the required expertise.

Empowerment and agency

One of the most commonly referred to aspects of all the activities was that of engagement and motivation; this has been classified under the feature of 'empowerment and agency' because it could be argued that by engaging learners, they may also be empowered to take ownership over their learning.

Increased pupil engagement was seen in particular as a benefit of access to real scientists and labs and use of digital games, as well as access to real scientific data and in one case arts and science activities. Low pupil engagement was perceived as a challenge in terms of using real scientific data, and in two cases arts and science activities.

A further relevant aspect was the potential of activities to allow learners to feel part of current research, both by using real data and accessing scientists and labs. Data was also seen to offer the chance to gain an increased understanding of the scientific method by involvement with real 'messy' data.

Access to real scientists and labs offered a range of opportunities for empowerment and agency in terms of future careers; respondents felt that these activities increased learner understanding of science careers, encouraged aspiration to these careers and may encourage recruitment. These activities were also seen to offer inspiration and authenticity. The Twitter debate offered some interesting data in this area, referring to the need to *'give*

The CREATIONS project has been funded with support from the European Commission under: H2020-EU.5., H2020-EU.5.a. Project reference: 665917

[learners] the tools to be free' and to allow them to pose their own questions and make mistakes.

Risk, immersion and play

Enjoyment was cited as one of the major benefits of both arts and science activities and digital games; this is quite a difficult theme to apply to a single one of the CREATIONS 'features', but it seems highly relevant here since digital games are characterised by connections to play, and arts and science activities offer much potential for risk, immersion and play. This was not always perceived as beneficial: *'Addictive gaming is a problem in school, whilst these immersive games give a way of exploring things, there is a balance in school to not encourage potentially harmful behaviours in children.'* Access to real scientists and labs hold potential in this area too, offering the opportunity for practical activities immersed in a real life context. In terms of risk, respondents referred to the need for teachers to be prepared to implement approaches involving holistic perceptions of teaching when planning arts and science activities, and to be prepared for wide-ranging questions and debate. There is a similar implication of the need for educators to take risks evident across much of the data, perhaps most evident in respondents' identification of the challenges of all of the different activities proposed.

Possibilities

In terms of the possibilities of thinking and space included within this feature, the benefits identified of each of the activities highlight their potential. More specifically, their capacity to make science real and make connections with the real world seems to support the provision of greater possibilities; this was emphasised most of all in terms of accessing real

The CREATIONS project has been funded with support from the European Commission under: H2020-EU.5., H2020-EU.5.a. Project reference: 665917

data, where relevance and authenticity was also cited as a considerable benefit. In response to the question about the connection between scientific inquiry and creativity, one of the most common responses concerned the need to think differently, 'think outside the box', and develop new ideas, an attitude which opens up a wealth of possibilities.

Ethics and trusteeship

Perhaps the most significant aspect in this area referred to the use of digital games, where their relationship to a wider digital and internet context was seen both as a benefit in terms of connecting to what is current and relevant for young learners, but also as a challenge because of the risks involved, as identified above and in respondents' views about internet safety and the potentially addictive nature of gaming. There were also two references made to the wider school community, in terms of demonstrating the value of activities to parents.

Key findings

- The CREATIONS features were all apparent in relation to the creative pedagogies identified and aid interpretation of benefits and challenges of creative use of Art/Science projects, digital games, virtual visits to real labs and access to real scientists and real data. Findings are summarised in Table 5

HORIZON 2020

The CREATIONS project has been funded with support from the European Commission under: H2020-EU.5., H2020-EU.5.a. Project reference: 665917

CREATIONS Features	Benefits	Challenges
Dialogue	Dialogue with real scientists Linking theory and practice	
Interdisciplinarity	Interdisciplinary skill development	Valuing different disciplinary cultures and vocabularies
Individual, Collaborative and Communal activity for change	Accessibility for all Enabling new perspectives	Accessibility of data Inclusion in real lab visits may not be feasible for all
Balance and Navigation	Modelling and generating creativity	Time, financial pressures, performativity cultures and curriculum constraints Maintaining focus on scientific knowledge and conceptual learning
Empowerment and Agency	Participation in current research	
Risk, Immersion and Play	Enjoyment	Risk in new and alternative pedagogies
Possibilities	Making real world connections opens possibility thinking	
Ethics and Trusteeship		Social/addiction risks in digital gaming

Table 7: Benefits and Challenges in Creative Pedagogies

The CREATIONS project has been funded with support from the European Commission under: H2020-EU.5., H2020-EU.5.a. Project reference: 665917

2.2.2 Key Implications for creative science pedagogies

These findings have several implications for creative science pedagogies, and, therefore, the future development of CREATIONS 'demonstrators'. Firstly, it is worth considering the distribution of current engagement with the activities which might contribute to them. The following table shows the numbers of respondents who, judging by their responses, had experience of each activity:

Science and Arts	Digital games	Access to data	Access to real scientists	'Other'
49	22	36	45	8

Table 8: Engagement with creative science education activities

The high number who had experienced arts and science projects is encouraging, as is the relatively even distribution across the respondents' nationalities and roles as primary, secondary or informal science educators of those who had experienced them. It may however reflect the sampling methods used for the survey; distribution was to contacts of the partners who because of the nature of the project may be more connected to people with experience in this area. The low number who had used digital games is of note and points to a significant further area for development, especially when considered alongside respondents' perceptions of the benefits and challenges of this resource.

The following image (Figure 3) summarises what could be categorised as 'best practice' in developing demonstrators. The cyclical arrows framing the image and encompassing the terms 'Accessible, Affordable, Available and Aspirational' indicate that these aspects should be taken into consideration whenever demonstrators are developed; the cyclical nature

The CREATIONS project has been funded with support from the European Commission under: H2020-EU.5., H2020-EU.5.a. Project reference: 665917

indicates that they are all interdependent. The 'bubbles' within the image also indicate elements that should be present within the demonstrator, perhaps to a greater or lesser degree depending on the specific nature of the activity (hence the overlapping shapes). However, the foregrounding of 'Focus on Scientific Learning' indicates that this aspect is fundamental to any demonstrator activity.

The CREATIONS project has been funded with support from the European Commission under: H2020-EU.5., H2020-EU.5.a. Project reference: 665917

Figure 3: Good Practice in Demonstrator Development

The CREATIONS project has been funded with support from the European Commission under: H2020-EU.5., H2020-EU.5.a. Project reference: 665917

2.3 What makes good training and professional development for a creative science educator?

There are two sections of the survey which provide insight into this question; firstly, the questions tailored to those working in teacher education, and secondly, the section on Teacher Education and Professional Development, which was answered by all those working in the formal education sector (excluding those working in teacher education). Due to the small sample size and considerable bias towards the USA within the teacher educator group, it was not considered worthwhile to analyse the data from this group according to the country of origin. However, comparisons between the small amount of data from the UK, other European countries and the USA do reveal some interesting results which would merit further investigation. Firstly, teacher educators in the UK compared to the rest of Europe seemed to have a narrower understanding of creativity in science education, with one asking 'What do you mean by teaching for creativity in science?' and another, cited above, referring to the potential tension between creativity and knowledge. Teacher educators from other European partner countries, by contrast, referred in four out of five cases to the need to make creative links with either existing knowledge, real world contexts or other disciplinary areas. One offered a perspective in distinct contrast to the UK teacher educator cited above:

'Making teachers understand that what matters for students the most is not memorising laws of physics but involving them in creative inquiry activities by stimulating their interest.'

Following the analysis of the qualitative data, four broad themes emerged:

- The learning environment and learner experience
- The content of training provision

HORIZON 2020
The CREATIONS project has been funded with support from the European Commission under: H2020-EU.5., H2020-EU.5.a. Project reference: 665917

- The quality of provision
- Peer support and the learning community

2.3.1 The learning environment and learner experience

Wide reference was made to the atmosphere required from the learning environment. Respondents felt above all that it should have a spirit of openness, characterised by curiosity, the possibility of risk-taking in an enabling and non-judgemental arena, and inclination to try out new ideas. Enthusiasm and willingness to participate were also cited. Empathy was considered important, as were qualities including patience, humility, humanity and listening.

The personalised nature of training was referred to in a number of ways; reference was made to autonomy and ownership over learning, alongside the need for training to be individualised, independent and allow for the development of self-efficacy. Individual motivation was also seen as a desired outcome from professional development.

2.3.2 Content of provision

It was much more common for science teacher educators and CPD providers to include IBSE in their courses compared with teaching for creativity in science. 92% of a total number of 50 teacher educators who responded to the survey said that they included IBSE in their courses (this equates to 1 respondent who did not include this, and 3 who were unsure), compared with just 50% including teaching for creativity. Professional development in integrating with other disciplines to teach for creativity was rarer still, with just 33% of respondents agreeing that this was part of their provision. 60% of respondents include teaching using dialogic pedagogy within their courses; higher than the statements

HORIZON 2020

The CREATIONS project has been funded with support from the European Commission under: H2020-EU.5., H2020-EU.5.a. Project reference: 665917

more explicitly about creativity but still perhaps surprisingly low. In a similar vein to IBSE, the use of digital technologies to engage pupils with science was included in 86% of courses.

It is evident that IBSE and digital technologies are both widely understood and included within teacher development programmes of the type whose leaders responded here. Teaching for creativity and dialogic pedagogy, on the other hand, seem to be less well understood and are certainly less integrated. The number of responses in the 'uncertain' category (regarding inclusion in teacher education programmes) for both of these elements suggests that definitions of what they are may be unclear to teacher educators. It is also interesting to note that 18% of the respondents stated that they actively do not teach for creativity, a slightly worrying statistic.

It is important to bear in mind the relatively small sample size of teacher educators when interpreting these percentages. This suggests that whilst teacher education and professional development appears to include elements of science pedagogy that can be explicitly linked to the features of creativity identified in the CREATIONS project D2.1, namely IBSE and dialogic pedagogy, other aspects of teaching for creativity in science are much less common. That the use of digital technologies is relatively commonly included is useful in the preparation of the CREATIONS demonstrators, many of which rely on teachers' effective use of digital technology to enable young people to access real data and virtual science laboratories.

It is also interesting to consider this data in comparison to the responses from primary and secondary teachers, who were asked whether they had either received training in IBSE or

The CREATIONS project has been funded with support from the European Commission under: H2020-EU.5., H2020-EU.5.a. Project reference: 665917

preparation to teach for creativity, and whether they had pursued any self-directed learning in these areas. Responses are shown in the following tables:

	Training in IBSE	Preparation to teach for creativity	Self-directed learning in IBSE	Self-directed learning in teaching for creativity
No	10	9	10	10
Yes	6	7	5	5

Table 9: IBSE and Creativity Training – Primary Teachers

	Training in IBSE	Preparation to teach for creativity	Self-directed learning in IBSE	Self-directed learning in teaching for creativity
No	27	30	18	26
Yes	11	8	21	12

Table 10: IBSE and Creativity Training – Secondary Teachers

This data reveals a particularly striking discrepancy between teacher educators' and secondary teachers' perspectives in the areas of both IBSE and teaching for creativity, where the numbers of teachers stating they had received training in these areas are considerably lower than the proportion suggested by the teacher educator data. These two figures obviously cannot be directly correlated as there is no specific connection between the teacher educators and teachers in terms of institution or even geographical location, but it is an interesting discrepancy to note. We tentatively suggest that this may be indicative of a rise in IBSE and creativity in teacher education in recent years. It is also interesting to be aware of the high proportion of secondary teachers choosing to engage in

HORIZON 2020
The CREATIONS project has been funded with support from the European Commission under: H2020-EU.5., H2020-EU.5.a. Project reference: 665917

self-directed learning in the area of IBSE, and the comparatively lower numbers electing to pursue such learning in the area of teaching for creativity. In terms of primary school teachers, a lower proportion had both received and pursued learning in IBSE, which has potential implications for transfer between primary and secondary education.

Respondents were also asked about the impact of both training and self-directed learning; the results are shown in the following tables:

	Training in IBSE	Preparation to teach for creativity	Self-directed learning in IBSE	Self-directed learning in teaching for creativity
High impact	1	4	3	5
Some impact	5	4	4	1
No impact	1	1	1	2

Table 11: Impact of IBSE and Creativity Training – Primary Teachers

	Training in IBSE	Preparation to teach for creativity	Self-directed learning in IBSE	Self-directed learning in teaching for creativity
High impact	6	2	8	6
Some impact	9	10	14	7
No impact	3	4	2	3

Table 12: Impact of IBSE and Creativity Training – Secondary Teachers

As can be seen from these tables, most responses fell in the 'high' or 'some impact' category in terms of both training and self-directed learning, with a relatively higher number in the some impact' category. 'Preparation to teach for creativity' for secondary

The CREATIONS project has been funded with support from the European Commission under: H2020-EU.5., H2020-EU.5.a. Project reference: 665917

teachers had a notably fewer number of 'high impact' scores', as did training in IBSE for primary teachers. The relatively high impact of self-directed learning in teaching for creativity on both primary and secondary school teachers, compared with the five teachers who stated that specific training in this area had no impact at all, is also interesting. This might point to a difficulty in developing effective training to teach for creativity, matched by a desire amongst teachers to find out more about this area (and to find the process of doing so independently impactful). This is also interesting when compared to the data regarding the features of effective teacher education, where 'creativity' was one of the most commonly cited elements. However, it is difficult to know whether this refers to creative teaching or preparation to teach creatively, which as previously discussed is not always an easy distinction to make for teachers and teacher educators.

In terms of the qualitative data in this area, the capacity of training to inspire and engage learners was viewed as significant by respondents. Innovative, challenging and thought-provoking approaches were appreciated. One of the most commonly identified features of effective teacher development, as stated above, was creativity and the use of imagination. Opportunities for problem solving, investigation, and participation in activities were seen as desirable, as was the need to develop participants' own thinking skills and creativity. Opportunities for reflection were considered to be very important, and some reference was made to possibilities for observation and feedback.

The most popular response in this category referred to the need for training to contain elements that were relevant, practical and immediately applicable in the classroom. Respondents felt also that training should be research and evidence based, and incorporate both pedagogical and scientific theoretical approaches. Respondents wanted to gain greater knowledge from training, both subject-based and in terms of greater understanding of

HORIZON 2020
The CREATIONS project has been funded with support from the European Commission under: H2020-EU.5., H2020-EU.5.a. Project reference: 665917

children's learning; some wanted the focus of training to be student-centred or to involve direct work with students. The concept that delivery should model the approach that should be used in the classroom was referred to frequently; for example, providing participants with open-ended tasks and investigations. Some respondents from the teacher educator group referred to introducing ideas of interdisciplinarity to training programmes.

2.3.3 Quality of provision

Respondents considered that teacher development should be systematic, ongoing, and forward thinking. They referred to the need for training to be rigorous and method-based. Affordable, accessible training was appreciated, as was effective use of time, both in terms of concise delivery and allowing space and time for reflection and discussion. Where general reference was made to the quality of provision, respondents referred to the importance of having well qualified and prepared training leaders, working in an environment of professionalism and well managed training.

2.3.4 Peer support and the learning community

Some respondents referred directly to the development of a peer learning community through training, both from the point of view of the training provider and the participant. Respondents also made reference to the opportunities for discussion, collaboration and the sharing of good practice. The notion of peer support in terms of coaching and acting as role models also appeared. The Twitter debate provides food for thought here; it was evident from the discussion that online environments can provide a significant level of both peer support and community, with participants in the debate exchanging lesson ideas, teaching resources, advice for effective interaction with other departments in schools, and a considerable amount of positive reinforcement and moral support. This is an area which is

HORIZON 2020

The CREATIONS project has been funded with support from the European Commission under: H2020-EU.5., H2020-EU.5.a. Project reference: 665917

worthy of further development and possible integration into teacher training programmes; some respondents cited ongoing support following training as valuable, and virtual communities might present an accessible means of providing this.

Key findings

- Professional Development in IBSE is more common and rated as having a higher impact than teacher education or professional development in teaching for creativity.
- Educators want professional development to be relevant, thought-provoking and have an immediate impact on pupil learning
- Professional development activities should model the approaches being advocated and develop educators' own knowledge, skills and creativity.
- Professional development should be accessible, affordable, rigorous and led by experts

The CREATIONS project has been funded with support from the European Commission under: H2020-EU.5., H2020-EU.5.a. Project reference: 665917

3. Effective teacher development: lessons from previous research

To complement the findings from the survey, key previous EU-funded research projects and literature were reviewed to synthesise lessons about effective teacher development. Search terms were identified using themes 'teacher development in IBSE' and 'teacher development in teaching for creativity in science', with simple searches conducted using google scholar and the British Education Index. EU projects included were: ESTABLISH, PATHWAYS, PROFILES, PRIMAS, SAILS and FIBONNACCI, where deliverables relevant to teacher education, development and support examined and synthesised.

Teachers' professional development programmes in IBSE were much more prevalent within the literature than those relating specifically to teaching for creativity in science, as indicated by the survey findings described in section 2.3.2 above. However, given the links already made between IBSE and pedagogies for teaching 'scientific creativity' (described in the CREATIONS deliverable D2.1), it is reasonable to suggest that models of effective professional development for educators grounded in evidence from IBSE implementations may also be effective in the context of teaching for 'scientific creativity'.

Important features of effective professional development identified across the literature included:

- Time
- Practical experience
- Pedagogical and Subject Knowledge
- Networking
- Assessment of student outcomes

The CREATIONS project has been funded with support from the European Commission under: H2020-EU.5., H2020-EU.5.a. Project reference: 665917

- Reflection
- Flexibility for adaptation to different cultures and curricula
- Teacher Agency

Demonstrably effective models of professional development were those in which educators (usually teachers in the literature reviewed) were allowed sufficient time to engage with developing their practice (90 hours is the optimal amount of time suggested by Supovitz and Turner, 2000), but this was regularly acknowledged as a key barrier given the time constraints for both teachers and students in terms of workload and curriculum time. The reason sufficient time is so important is because of the necessity to enable educators to experience the learning for themselves before trialling it in practice, reflecting on the experiences and taking responsibility for developing the practice. A simple 'one-off' input offered by an expert was found to be insufficient in embedding changes in practice (McLoughlin, 2011; PRIMAS, 2011). Thus, motivating teachers to give one of their most valuable resources, time, to developing their practice in any given area is crucial for effective teacher growth.

A key way in which teachers are motivated to engage in professional development is through evidence of impact on student outcomes (PRIMAS, 2011) as it is through clear impact on students' that teachers' attitudes and beliefs about particular pedagogies are changed (Guskey, 2002). This means that incorporating support for teachers with the difficult challenge of assessment of IBSE and creativity is key to effective CPD, but is one of the most challenging elements due to the often open-ended nature of the activities undertaken by the students combined with frequent curriculum constraints in the teaching

HORIZON 2020
The CREATIONS project has been funded with support from the European Commission under: H2020-EU.5., H2020-EU.5.a. Project reference: 665917

of specific content and skills. The SAILS project[2] was designed to research and develop support for teachers with the assessment of inquiry, and the use of appropriate formative, dialogic assessment was also advocated within the PATHWAYS project. These suggestions draw on pre-existing evidence about what makes quality assessment-for-learning (AfL). For example, the SAILS project, having identified a range of IBSE 'competencies', offer a selection of tools that may be used to assess student outcomes in a flexible manner. These include classroom dialogue, teacher observation, peer and self-assessment, student-devised assessment materials and presentations, as well as worksheets or quiz-based items. Using similar approaches in professional development for teaching for scientific creativity using the CREATIONS demonstrators is also anticipated to support educators in using dialogic teaching strategies; thus also supporting teacher growth with respect to dialogue, a key CREATIONS feature of creativity.

The CREATIONS feature 'Agency and Empowerment' is both developed and supported within effective teacher development programmes, as advocated in the literature, through opportunities for networking with other teachers (ESTABLISH[3], FIBONNACCI[4]), active engagement with implementing and developing teaching strategies to ensure a sense of ownership (PROFILES[5], SAILS, ESTABLISH), and through reflecting on and enacting change (PRIMAS[6], PROFILES).

Strategies that enable such active engagement by teachers include Action Research and Lesson Study, and Study Groups. Approaches such as these are advocated as a powerful

[2] http://www.sails-project.eu/portal
[3] http://www.establish-fp7.eu
[4] http://www.fibonacci-project.eu
[5] http://www.profiles-project.eu
[6] http://www.primas-project.eu/en/index.do

HORIZON 2020

The CREATIONS project has been funded with support from the European Commission under: H2020-EU.5., H2020-EU.5.a. Project reference: 665917

mechanism for transformative teacher growth (PRIMAS, 2011) and the development of educators' scientific and pedagogical content knowledge (Shulman, 1986). The importance of both scientific knowledge and pedagogical content knowledge was raised across the full range of projects and literature explored, with the fact that IBSE requires very specific Pedagogical content knowledge regularly noted (e.g. PATHWAY, nd). Practical experience was deemed important in developing this crucial aspect both within the literature reviewed and in the CREATIONS survey findings. First-hand experiences that allow educators to understand the student experience before implementing and developing material themselves is an important element of effective CPD (Jonsson et. Al 2012). This could be achieved through the use of case studies, role play, simulations, working with professional scientists and learning cutting-edge science, and the use of digital technologies, as well as through participation in inquiry in an area with which they are unfamiliar with the content (PATHWAY, nd). As highlighted above, as well as introducing teachers to IBSE and Creativity via such 'immersion' experiences, educators' subsequent implementation of the new pedagogical approaches, followed by reflection and review, is crucial in developing educators' pedagogical content knowledge as well as fostering a sense of agency and empowerment. The ESTABLISH project also advocated the importance of fostering a sense of ownership and agency through opportunities for teachers to work with industry professionals to develop their industrial content knowledge (McLoughlin, 2011), and this can be adapted within the CREATIONS project through opening opportunities for teachers to work with professional scientists.

Where professional development materials are likely to be used across a range of national contexts, as is the case in all EU-funded consortium projects such as those described here and the CREATIONS project itself, the materials must be sufficiently flexible to be adapted

HORIZON 2020

The CREATIONS project has been funded with support from the European Commission under: H2020-EU.5., H2020-EU.5.a. Project reference: 665917

to the relevant cultural and curricula contexts. To enable flexibility and adaptability of any model of professional development in IBSE and creativity, the provision of a combination of 'core' content with 'supporting units' was found to be an effective strategy (McLoughlin, 2011; Jonsson et. Al, 2012). Similarly, the PRIMAS project developed a flexible suite of modules for teacher development in relation to various challenging aspects of IBSE pedagogy (PRIMAS, 2011). The content of the 'core' and 'supporting' units varied depending on the focus of the project (see table 9 for examples). Core modules were primarily focused on understanding IBSE and the implementation and development of IBSE in the classroom, with further modules exploring some elements in depth, such as assessment, argumentation/collaboration and the use of ICT. Many of these modules may be usefully adapted to support educators using the CREATIONS demonstrators to teach for scientific creativity.

	ESTABLISH	**SAILS**	**PRIMAS**
Core Modules	ESTABLISH view of IBSE	Experiencing Inquiry and Assessment	Student-led inquiry
	Science Teacher as Implementer	Trialling IBSE and Assessment in the Classroom	Tackling unstructured problems
	Science Teacher as Developer	Developing IBSE and Assessment Resources	Learning concepts through inquiry
	Industrial Content Knowledge		Asking questions that promote IBL
			Students working collaboratively
Supporting Modules	Research and Design projects for students	Facilitating and Assessing Group Work	
	Assessment of IBSE	Developing Assessment Criteria and/or learning progression	
	Argumentation in the	Facilitating and	

The CREATIONS project has been funded with support from the European Commission under: H2020-EU.5., H2020-EU.5.a. Project reference: 665917

	classroom	assessing student argumentation	
	ICT	Providing students with productive feedback	
		Using ICT in Assessment	

Table 13: Synthesis of modules in IBSE training programmes

The synergy between the outcomes of the survey conducted for the CREATIONS project and the previous project findings reviewed enables some well-founded conclusions to be drawn regarding the important considerations and strategies for effective professional development of educators in teaching for creativity in science education. Effective professional development offers:

- Affordable, evidence-based, rigorous, concise and accessible input, combined with opportunities for practical experience, implementation, reflection and further development;
- Clear opportunities for measurable impact on student outcomes, with support for how to assess this impact;
- Opportunities for networking and review following implementation and reflection;
- Subject and pedagogical content knowledge development.

The CREATIONS project has been funded with support from the European Commission under: H2020-EU.5., H2020-EU.5.a. Project reference: 665917

4. Conclusions

Following analysis of the quantitative and qualitative survey data, cross-comparison with wider research into good practice in teacher training and development in terms of IBSE, and bearing in mind the limitations imposed by the sample size and limited geographical spread of the respondents, it is possible to draw conclusions linked to the research questions outlined in the introduction which relate to current and existing practice in teaching, teacher education and creative science pedagogies within and outside the classroom. These conclusions will be presented in terms of their implications for informal science educators, scientists and teacher trainers, and with reference where relevant to the CREATIONS features. It is important to bear in mind that the profile of a creative science educator has been previously addressed in the CREAT-IT project; the current data and analysis adds further insights to this. A further point to note is that D2.2 of the current project is centred around teacher development with the provision of resources to help educators develop their ability to become creative science educators.

4.1 Implications for informal science educators

Given the strong links between creativity and scientific inquiry stated by informal science educators, it is clear that there is currently an understanding within this sector of the inherently creative nature of science. However, taking into consideration the tendency of teachers to link creativity more specifically to the processes of scientific method, it may be worth considering **how these links can be made more explicitly in informal science learning situations**. A further identified need in informal science learning is that of remaining focused on the science learning at all times – **other activities should not be a 'distraction' but a vehicle for pupil engagement, enjoyment and inclusion.**

The CREATIONS project has been funded with support from the European Commission under: H2020-EU.5., H2020-EU.5.a. Project reference: 665917

4.2 Implications for scientists

It is evident from the data that opportunities to engage with 'real' scientists, scientific work and actual data are considered by teachers to be engaging, enjoyable and motivating for students, and to offer possibilities of breaking down stereotypes and demystifying science, the identity of scientists and careers in the sciences. **Scientists should therefore be prepared to build on the capacity for engagement with education activities to demystify science and pave the way for science careers.** The main barriers identified in this area were the ability of scientists to communicate their knowledge in an accessible manner, the physical accessibility of laboratories and relevant organisations, the willingness of both scientific institutions and scientists to engage in such activities, and the complexity and relevance of the data available. It is fundamental therefore that both individuals and organisations:

- Identify opportunities to provide training and opportunities for scientists to develop their ability to communicate their knowledge to young audiences
- Consider how to make their spaces accessible to groups of learners, either physically or virtually
- Recognise the value for the future of science in engaging with education activities and their capacity as scientists to inspire the next generation to consider careers in the sciences
- Identify and disseminate datasets which are accessible and relevant to learners at all levels, not just upper secondary. If possible, provide support and training for teachers who may also find interpreting such data challenging.

The CREATIONS project has been funded with support from the European Commission under: H2020-EU.5., H2020-EU.5.a. Project reference: 665917

Given that an identified issue in interdisciplinary/arts based projects and digital games is the quality of the science knowledge included, scientists could also consider working with project leaders on interdisciplinary projects and in the development of digital games to provide the required 'science knowledge'. Again, as these activities have been identified as engaging, enjoyable and motivating for learners, it is a useful investment of scientists' time to work collaboratively in this way, if securing the future of scientific investigation is a priority.

4.3 Implications for teachers

The data shows an overall positive perception amongst teachers of the relationship between science and creativity, as evidenced by the 'creativity scale', and of creative science pedagogies. The stated challenges of curriculum time, the pressure of performativity and the testing and exam culture were no surprises; the data broadly reinforced the expected findings from a sample of this size and type, particularly amongst the UK secondary school teachers. **The capacity (and need) to balance creativity and knowledge at secondary level** is a significant challenge for teachers, and the potential to view **creativity as a challenge to knowledge transmission and retention** is potentially problematic; it is important to consider the ability of the CREATIONS features, when used effectively in the classroom, to address this issue, particularly in terms of **balance and navigation.** The data highlighted the connection that teachers saw between creativity and each stage of the **inquiry process**; embracing the potential of the CREATIONS demonstrators to harness opportunities for **possibility thinking** and for **individual, collaborative and communal activities for change** could allow for this connection to be embedded even more firmly.

The CREATIONS project has been funded with support from the European Commission under: H2020-EU.5., H2020-EU.5.a. Project reference: 665917

Those teachers who had experienced contact with 'real scientists' identified the possibilities for dialogue offered by these activities; teachers should **seek out and facilitate opportunities for real and virtual dialogue with science** in all its forms. The links between creativity and question posing were also clearly identified; **entering into dialogue with learners, focussed around questioning and allowing pupils to ask the 'wrong questions'** can enable a more creative pedagogical approach.

Arts and science projects were portrayed positively by those who had participated in them, with the caveat that science subject knowledge must be rigorous and that the focus on science learning must be maintained; however, their capacity to **develop creativity, include all learners, encompass different modes of learning, allow new ways of seeing, and develop transferable skills** alongside their capacity to provide **holistic, enjoyable, engaging opportunities for learners** should be embraced by teachers. The limiting factors of time, costs and the performativity culture of education cannot be ignored; nevertheless, the benefits of arts/science projects to impact both on scientific learning and broader pupil engagement are clearly perceived by teachers. Teachers' willingness **to take risks and engage with activities beyond the classroom**, that can significantly impact on pupil engagement, enjoyment, and skill development, is crucial here.

The data identified the potential for **empowerment and agency** across a range of activities; allowing learners to **take ownership over their learning** particularly in terms of **independent generation of questions and novel approaches to problem solving** is an effective way of putting creative pedagogies into practice in the classroom.

HORIZON 2020

The CREATIONS project has been funded with support from the European Commission under: H2020-EU.5., H2020-EU.5.a. Project reference: 665917

4.4 Implications for teacher educators and the professional development of educators

The data illustrates that although provision of training for IBSE by teacher educators is relatively common amongst the sample (bearing in mind the North American bias), teacher perception of the content and impact of training in this area is more measured, which would suggest that further emphasis needs to be placed on **training for IBSE, especially in primary teacher training contexts.** Teaching for creativity is far less common, and therefore teacher educators should **prioritise explicit teaching for creativity** bearing in mind and openly addressing **the potentially different conceptions of creativity within and outside science** that exist. Becoming clear in their own minds about the nature of 'creativity' in a science education context, and what 'teaching for creativity' means will be a first step, and dissemination of the findings of the CREATIONS project as a whole to teacher educators and teacher training providers will be a priority. It is also important for teacher educators to consider the potential tension between 'creativity' and 'knowledge', and to model by their own delivery the ways in which **creativity and knowledge can be mutually supportive rather than oppositional**

Modelling good practice in independent generation of scientific questions is fundamental; data from teacher educators suggested that their 'modelling' function was seen as important in many cases, and this is an area where early career teachers can be directed towards effective, creative pedagogical approaches. Teacher educators should also **prioritise access to creative pedagogical approaches through experience** of them, for example by arranging access to labs and scientists, and working with real scientific data.

HORIZON 2020

The CREATIONS project has been funded with support from the European Commission under: H2020-EU.5., H2020-EU.5.a. Project reference: 665917

Teacher educators should also be aware of the potential barriers to interdisciplinary learning, and make use of opportunities to **explore different vocabularies and discourses to make links between disciplines (and between branches of science).** A valuable opportunity in university based training is offered by the existence of different departments; teacher educators could explore the possibility of **making links between departments at universities in interdisciplinary projects and learning** (or if training is school-based, between school departments and teachers), therefore embedding good practice from the beginning of teachers' career and potentially **addressing differences in discipline communication, vocabularies, and means of working.**

In terms of strategies for the provision of effective professional development, evidence suggests that **accessible, flexible core provision related to subject and pedagogical content knowledge needs to be combined with opportunities for educators to explore teaching strategies first-hand and take ownership of their development.** Given that impact on students is the most important facet in enacting and embedding new teaching strategies, **support with assessment of student outcomes should be included within the professional development offered.** Finally, including **the opportunity to develop strong networks with peers, 'facilitators/providers' (ie teacher educators or CPD providers) and scientists** supports reflection, empowerment and ultimately teacher growth.

HORIZON 2020

The CREATIONS project has been funded with support from the European Commission under: H2020-EU.5., H2020-EU.5.a. Project reference: 665917

References

Guskey, T.R. (2002). Professional Development and Teacher Change. *Teachers and Teaching: theory and practice,* 8 (3-4), 381-391.

Jonsson, A., Lundstrom, M., Finlayson, O., McLoughlin, E., McCabe, D. (2012) Report on IBSE Teacher Education and Assessment programme - Stage 1. Strategies for the Assessment of Inquiry Learning in Science (SAILS). http://www.sails-project.eu/sites/default/files/d4.2_report_on_ibse_teacher_education_and_assessment_programme-stage1_0.pdf

McLoughlin, E. (2012) ESTABLISH: D5.2 Framework for Teacher Education Programme. European Science and Technology in Action: Building Links with Industry, Schools and Home. http://www.establish-fp7.eu/sites/default/files/general/ESTABLISH_D5-2_FRAMEWORK_TEACHER_EDUCATION_0.pdf

PATHWAY (nd) Teachers' Professional Development: The Pathway to Inquiry-Based Science Teaching. http://pathway.ea.gr/content/teachers-professional-development

PRIMAS (2011) PRIMAS Guide for Professional Development Providers. The PRIMAS project: Promoting inquiry- based learning (IBL) in mathematics and science education across Europe. http://www.primas-project.eu/servlet/supportBinaryFiles?referenceId=2&supportId=1300

Shulman, L. (1986) Those who understand: Knowledge growth in teaching. Educational Researcher, 15(2), 4- 31

HORIZON 2020

The CREATIONS project has been funded with support from the European Commission under: H2020-EU.5., H2020-EU.5.a. Project reference: 665917

Supovitz, J. A. and Turner, H. M. (2000) *The Effects of Professional Development on Science Teaching Practices and Classroom Culture* Journal of Research in Science Teaching 37 (9) p. 963-980.

The CREATIONS project has been funded with support from the European Commission under: H2020-EU.5., H2020-EU.5.a. Project reference: 665917

Appendix 1

A principal axis factor analysis was conducted on the ten relevant survey items with orthogonal rotation (varimax). The Kaiser-Meyer-Olkin measure identified an acceptable sampling adequacy of 0.803. However, three items had KMO values of <0.5, indicative of the low sample size, suggesting that the results of the exploratory analysis should be used with care (Field, 2013). Where factors with eigenvalues >1 were requested, three factors were extracted but the scree plot was ambiguous, with a turning point at 3, suggesting the extraction of two factors might be more appropriate, particularly given the sample size. Extracting two factors explains 49% of the variance and reduced non-redundant residuals to 55%: this again indicates limitations on the model suggesting interpretation of these factors should be conducted with care. It is possible that this is a result of the inclusion within the scale of questions relating to both an overall perspective on the relationship between science and creativity, and how this is explored within an educational context. Should this survey be repeated with a larger sample, it will be important to clearly separate questions relating to a general perspective on science and creativity from questions exploring this relationship in educational settings. Despite this, exploratory factor analysis suggested the removal of the item 'creativity in science is individual' from both scales, leaving one scale composed of items relating science and creativity using various aspects of the CREATIONS features and their relationship with scientific inquiry and the nature of science, and one scale composed of two items focused on scientific knowledge and scientific method, which appears to be a sensible interpretation. The main sub-scale was labelled 'scientific creativity' for the purposes of the initial analysis. Testing for reliability of this sub-scale suggests it is reliable (Cronbach's alpha = 0.822, with alphas in the range 0.771 to 0.824 if items are deleted). The second pair of items, indicated in the table below

HORIZON 2020

The CREATIONS project has been funded with support from the European Commission under: H2020-EU.5., H2020-EU.5.a. Project reference: 665917

as 'disciplinary science', do not form a reliable scale (Cronbach's alpha = 0.414) and will thus be analysed separately.

The CREATIONS project has been funded with support from the European Commission under: H2020-EU.5., H2020-EU.5.a. Project reference: 665917