Reviewing the potential and challenges of developing STEAM education through creative pedagogies for 21st learning: how can school curricula be broadened towards a more responsive, dynamic, and inclusive form of education?

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A report from one of the BERA Research Commissions
REVIEWING THE POTENTIAL AND CHALLENGES OF DEVELOPING STEAM EDUCATION THROUGH CREATIVE PEDAGOGIES FOR 21ST LEARNING:
HOW CAN SCHOOL CURRICULA BE BROADENED TOWARDS A MORE RESPONSIVE, DYNAMIC, AND INCLUSIVE FORM OF EDUCATION?

The first phase of the BERA Research Commission consisted of two seminars held at the University of Exeter. Invited participants included representation from the BERA Practitioner Research SIG, the Association for the Study of Medical Education, the British Medical Journal and Universities’ Council for the Education of Teachers and from 3 of the 4 jurisdictions of the UK. The first seminar was held on the 11th February 2016 and focused on ‘Using evidence to inform policy and practice in teacher education and medical education’ and the second seminar on the 25th April 2016 focused on ‘Understanding Cost, Value and Quality in professional education’. The seminars were recorded and working papers to accompany the seminar series were produced. The recordings and working papers are available on the project website: http://socialsciences.exeter.ac.uk/education/research/projects/projectlinks/beracommissionprofessionallearning/

The Commission adopted the structure of a parliamentary select committee by calling upon expert witnesses to outline a case illustrating their approach to the management of questions of cost, value and quality in professional learning. The two seminars were designed to promote the presentation and interrogation of evidence from alternating perspectives; Seminar 1 focused on cases presented by expert witnesses with a background in education and Seminar 2 on cases presented by witnesses with expertise in the economics of education. Each seminar included cases drawn from teacher education and medical education in the four jurisdictions of the UK and questions to each expert witness fled to a community of inquiry involving all participants. The outcomes of the first seminar were captured by mapping the issues and themes and this map was used to guide the proceedings in the second seminar and continues to be used as a reference point for the Community of Inquiry (see Appendix 1). The second seminar concluded with the identification of important areas for further collaborative research and these are shaping the formation of collaborative partnerships and activity in the next phase of the Commission:

• Institutional allocation of academic staff workload hours as a possible way of ‘costing up’ teaching activities, modules and programmes.

• In terms of recruitment crises and fast track teacher-training programmes, is it possible to evaluate the cost, value and quality of these different routes into training? In other words, to understand the evidence base for political decisions - is it just time taken or particular components of the training? (note literature on development of expertise)
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This project was conducted under the auspices of the British Educational Research Association (BERA) which provided the impetus, infrastructure, and support for the initiative. It is one of three Research Commissions funded in 2015-2016 with the aim:

“To explore how educational research can respond to the challenges and opportunities raised by the changing nature of education across the four nations”.

Set out as a scoping exercise, involving different jurisdictions in the UK, the commission engaged with the concept of STEAM education, a hybrid concept arising at the intersection between conceptions of science and the arts. The review considered three interconnected areas: (1) the changing conceptualization of science and arts, and the implications for science education; (2) the relationship between formal school science as it is currently taught and the differential access to science knowledge affecting groups inside and outside schools; (3) the potential of arts-based creative pedagogies to foster inclusive, participatory, and interdisciplinary learning in science.

Firstly, the Commission undertook a review of literature and practices concerned with how creativity, and the arts, are engaging with science, technology, engineering, and mathematics, in education; and identified potentially fertile areas for further research and practice development.

Secondly, a series of Extended Dialogues focussed on projects which self-identified as ‘STEAM’ and related approaches, as well as identifying diverse practices that appeared to draw substantially on ‘the arts’ or creativity in pursuing STEM education; the so-called STEM to STEAM agenda. We focused on the nature of the relationship between different projects, and the lessons to be learnt from literature within this purview.

The commission also drew together a range of stakeholders including science and arts practitioners, educationalists, and members of the STEM higher education community for a series of open discussions. Sampling for membership of these groups was opportunistic, primarily through the contacts of the local organiser with some ‘snowballing’ through contacts of those initially invited. Membership was diverse and included: teachers, local policy makers, external STEM and STEAM organisations, educational consultants and higher education academics in STEM subjects or education. From these discussions, several themes emerged as having significance for our understanding and development of STEAM education related practices. Whilst no claim can be made that these themes ‘represent’ the specific views of any group, the broad membership did allow for a range of perspectives to be heard and woven into this final report.

Further informal discussions occurred with practitioners, policy makers, academic colleagues, and teachers about the emerging themes from these open discussions and their educational implications.
These discussions recognised the devolved nature of education in the UK, including the emerging convergence of some aspects of curriculum and educational priorities in Scotland, Wales, and Northern Ireland. Conversations also occurred with several overseas colleagues, in Europe, New Zealand, Australia, Asia, Scandinavia, South America, and the USA. These helped to differentiate broader, ‘global’ issues in science and STEM education and the arts, and the more local issues.

In summary, this report sets out the broad contours of the ‘state of play’ both in terms of practice and emerging literature. Much more work would need to be done to present a comprehensive and complete picture of STEAM education in the UK. Further, it sets out concerns, challenges and questions raised in the process of focussed conversations with colleagues around contemporary limitations of science education, the potential for future development and helpful ways for practitioners and researchers to conceptualise the field.

**KEY FINDINGS**

1. **Conceptual difficulties**
   A difficulty in critically reviewing the literature, and understanding the perceptions and practices, as gleaned through conversations with practitioners, was the lack of conceptual clarity with respect to the key terms used. Whilst STEM has currency as an essentially economic term identifying those educational areas that have greatest impact on a developed country’s GDP, the pedagogical and curricula implications are less obvious. STEAM retains this lack of educational clarity, indeed adds to it, firstly: by being itself a portmanteau term; secondly, by having varied modalities and associated purposes; and thirdly, because the terms ‘art’ and ‘arts’ are also used interchangeably, and often uncritically. Thus, it is unclear if ‘art’ or ‘arts’ refer to, for example, the arts, or specific art forms/practices, or pedagogies used in teaching art subjects or arts and humanities. It is also unclear whether STEAM is intended to imply a reconfiguration of disciplinary relationships, interdisciplinary and/or transdisciplinary conceptions of the subject. Further, it is unclear whether an arts-infused or arts-integrated approach is implied. Whilst this poses no difficulties for individual case studies, either in educational or professional practices, or reported in the academic literature, the lack of conceptual clarity limits the possibilities for a comprehensive account to be developed. The conceptual issues are further complicated by an apparent conflation of STEAM with creative approaches to teaching in the STEM subject areas, which the commission recognises as encompassing significantly different purposes.

We recognise that STEAM education as a concept is situated, contested and contextual. In this review it will be argued that this contested nature relates to alternative worldviews in education which have become a new arena of intense interest for Re-Thinking Education Globally (UNESCO, 2015). Where the underpinning concepts are clearly stated, STEAM education offers a fertile space to consider ways of developing STEM education. However, lack of conceptual clarity is unhelpful in making any general claims, and comparing like with like. In summary, we found the lack of clarity problematic. **We recommend:**

(1a) there is a need for further philosophical work setting out the various concepts/conceptions of STEAM and offering some illuminative taxonomy of the relationships between diverse conceptions.
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(1b) There is a need for researchers, in particular, to be more explicit about the concept/conception of STEAM to which they are referring.

(1c) There is a need for researchers to locate their research in particular traditions and arguments about STEAM education.

(1d) There needs to be more conceptual work on what might be meant by ‘arts’ and ‘the arts’ and ‘creativity’ in relation to STEM/STEAM approaches to education.

2. Key foundational issues
Initial collaboration between members of the Commission identified key themes to which attention was paid during the stakeholder activities and literature review. These themes related to investigable questions that were embryonically part of the original Commission proposal. They were clarified and developed further during the process. Whilst we recognise interrelationships, for example, that ontological issues are connected to methodological, epistemic, and axiological issues, for ease of discussion the themes are presented separately.

• To what extent are debates on the epistemic and ontological foundations of STEM/STEAM subjects impacting on educational research?

Questions relating to epistemic and ontological issues were identified throughout the Commission’s activity. There are indications of interest in a number of these issues by educationalists. We recommend:

(2a) systematic consideration of the potential implications of debates in the philosophy and sociology of science on STEM/STEAM, and particularly, science education.

(2b) Opportunities for educationalists, philosophers of science, scientists and policy makers, and professionals to discuss how these ontological and epistemological issues might shape educational debate on STEM/STEAM education.

(2c) Consideration of the pedagogical and curricula implications of trans/inter disciplinary thinking.

(2d) Consideration of the educational implications of such debates for school curriculum and pedagogy in general.

• To what extent does STEM education engage with the socio-political aspects of science and technology (and how might STEAM enhance this engagement)?

Several concerns are emerging with both the social role of STEM, especially science, education, and with its content. Whilst some of these relate specifically to education, many reflect broader shifts in societal concerns. Three main themes were identified: more criticality with regards to the role of science in supporting particular models of industrial development, the dominance of perceived economic imperatives in the formation of science curricula and pedagogy, and the dual role of
educating to develop scientifically literate citizens as well as to inspire and enable future scientists. **We recommend:**

(2e) a review of the purpose of science education in schools.

(2f) An investigation into pupils’ understanding of the role of the sciences and STEM subjects in society.

(2g) Systematic consideration of socio-political dimensions of science education.

(2h) A consideration of the potential for the inclusion of STEM in other curriculum areas, for example, citizenship, personal and social education.

(2i) A review of the specific needs of employers in relation to STEM/STEAM outcomes.

- To what extent does STEAM education impact on the engagement of groups usually ‘disengaged’ from STEM subjects, especially by gender or poverty?

The Commission considered the evidence of the disengagement of specific groups in terms of the take up of Science at Level 3 and above. Women and pupils from lower socioeconomic classes tend to be underrepresented. The physical sciences show a lower uptake from these groups than the biological sciences. There is already good evidence of the reasons for this and para-school structures in place to respond. Whilst there remains little evidence that STEAM projects can support young people, and especially girls’ views of themselves as scientists; this little evidence does suggest that STEAM projects have this potential. The significance of arts-based processes and perspectives, which emphasise embodied and relational dimensions, is clear. **We recommend:**

(2l) Further and extensive mapping of the outcomes of STEAM projects against known mechanisms for increasing girl’s and women’s involvement in STEM subjects.

(2m) Investigations into the impact of STEAM projects on pupils from lower socioeconomic groups and its potential for improving engagement with STEM subjects.

- What do we understand by the role and significance of the arts, and what constitutes creativity in STEM education?

In addition to the conceptual questions identified in §1, the Commission considered the literature on creativity/creativities in education more broadly, and the distinctive contribution of the arts in relation to different STEAM projects. There was clear evidence of creative approaches to STEM teaching which motivated pupils, however, these projects tended to be ‘one off’ or short term, and externally staffed. **We recommend:**

(2n) greater consideration of requirements for sustaining STEAM education in schools.

(2o) Greater consideration of the distinctive role of creativity for education in each of the STEM subjects.
(2p) Further investigation of the distinctive processes and practices in both the arts and the sciences, and what they have in common.

(2q) Detailed consideration of the relationship between the arts and both broad and subject specific conceptions of creativity for STEAM education.

(2r) Proactive and critical profiling of the reciprocal relationship between arts and sciences in fostering different educational paradigms.

• What is the value of STEAM approaches compared to other approaches to STEM education?

Whilst the review considered the evidence on the perceived value of particular projects, there is little attempt to compare STEAM education with other approaches. In part this reflects, with a few exceptions, the short-term nature of many projects in the UK. International evidence provided little direction, though signalling a more detailed alignment with curriculum objectives. We recommend:

(2s) detailed consideration of STEAM’s distinctive contribution to both learning in STEM subjects and to generically valued skills.

(2t) Reviews of quality of science specific learning (content and skills) in STEAM contexts in relation to other approaches.

(2u) A ‘value for money’ assessment of STEAM approaches in respect to other approaches to STEM education, which takes account of both STEM subject achievement and broader learning skills.

(2v) A review of the political value of STEAM to support broader educative agendas, including empowerment, new forms of assessment, learner-teacher relations, and reaffirmation of the contribution of arts education.

3. Further emergent themes

Whilst §2 reflects the main considerations and recommendations of the Commission, further issues emerged in the debates with stakeholders and from the literature. We recognise that these concerns are replicated in distinctive STEM agendas and any further work in STEAM needs to relate closely to on-going practice and research in STEM education. These issues reflect, primarily, the concerns of practitioners, HE colleagues and educationalists working in the domains of STEM, and Arts subjects. They are stated without commentary. We recommend:

(3a) there is a need for explicitly building on previous research and scoping the possibility of meta-studies. We suggest that research projects be encouraged which provide the necessary credentials to be included in future meta-studies.

(3b) There is a need for close-to-practice and practitioner literature to pay more attention to the broader literature on creativity and arts in education.
(3c) There is a need for attention to be paid to the differential status within the curriculum of the four ‘disciplines’ of STEM which, in part, appears to be shaped by their relationship to arts subjects in school.

(3d) There is a need for future work exploring the possibilities of STEM subjects contributing to, and being taught within, arts and humanities classrooms. There is some evidence of this, which is limited to the primary school, but this may be a fertile site for its development.

(3e) There is a need for further consideration given to the contribution, and inclusion, of the humanities to STEM/STEAM education.

(3f) There is a need for further comparative studies, across jurisdictions in the UK and internationally. This ought to specifically consider the potential of STEAM education in relation to different institution and curricula arrangements.

(3g) There is a need for more detailed work on understanding and conceptualisation of student progression across all phases (primary to tertiary) in relation to STEAM. This should pay particular attention to examinations, career trajectories and entry requirements for ‘recruiting’ higher education institutions.

(3h) There is a need for further opportunities for employers, arts and science practitioners, teachers, educators, and STEM academic staff to discuss and inform each other’s work.
1. INTRODUCTION

This project, funded by the British Educational Research Association (BERA) is one of three Research Commissions tasked:

“To provide both theoretical rigour and an evidence base that can help set the strategic direction and aspirations of BERA and influence how it engages with other learned societies, Research Councils, Government and the education community more broadly”.

What this meant more specifically, was that the purpose of the Research Commission was to facilitate critical dialogue among educationalists, social scientists, artists, and practitioners looking at the educational opportunities and challenges suggested by the term and practice identified as STEAM education.

In an increasingly technological world, a practical necessity arises to educate young people to be more capable and confident in the STEM subjects; such necessity is also identified from a perceived economic imperative, which is to provide for a more STEM educated workforce. Thus, as we identify throughout the report, there are positive drivers for developing an effective STEM education, both shaping and being shaped by broader political, and global discourses. However, we also recognize the potential risks of failing to address critical dimensions of the role of science and technology in society, how they operate in the global environment, and how such considerations may challenge developments within STEM subjects. Education in STEM disciplines ought, we note, to be more than induction into the content and practice of those disciplines. There is an educational need to explore controversy within, and about the STEM disciplines.

Such a view of education locates recent interest in the inclusion of the ‘A’ within STEM. Firstly, there are arguments that the arts and creative approaches will contribute to the effectiveness of STEM education. Secondly, that the inclusion of the arts emphasises the possibility of multi and trans-disciplinary practices, reflecting long-held, historical, social, and educational views of the arts and sciences as naturally connected. Thirdly, it identifies the value of the arts in promoting an engagement with ‘the human condition’, the values we collectively espouse, and the productive exploration of controversial issues. Thus, it is argued, the arts offer diverse and engaging modes for individuals and societies to approach, articulate and process experience.

In the process of pursuing dialogue amongst competing viewpoints, we experimented with diverse activities and dialogic practices which led us to develop what we called “Extended Dialogues”. Dialogues were held throughout the course of the review, across the geographical regions of Scotland and England, involving diverse groups of participants. This review sought to consider the ways in which STEM education is being and could be approached, which might draw on practices deemed as creative or incorporating arts-based approaches.
Unsurprisingly, conceptual difficulties and tensions characterised this research. The composite nature of the term STEAM inevitably highlighted a multiplicity of epistemological framings and languages pertaining to different traditions of inquiry. Power hierarchies amongst different disciplines are also acknowledged, and these contributed to multiple, possible configurations of STEAM practices.

This report includes a brief account of the review approaches, survey of literature and dialogues conducted. Fuller accounts, including recordings of presentations are available on the project’s website: https://steamresearch.wordpress.com. In the spirit of the dynamic nature of this inquiry, we wish to invite readers to contribute comments and disseminate information via the twitter account: @steamresearch

1.1 SITES OF CONTESTATION

An inquiry into STEAM education involves consideration of STEM subjects (science, technology, maths, and engineering), in relation to the character of, and particularly the purpose for interfacing with, the arts and creative pedagogies. Yet STEM, the arts, creativity, and education are themselves each sites of contestation, with different groups bringing separate concerns, perceptions, and often contradictory expectations to the same arena. It is helpful to take notice of three areas of contestation to which we have returned as a commission on several occasions, which are critical for understanding opportunities and constraints related to the idea of STEAM.

These are: the nature of science and its relationship to science education, the importance of the arts and creative pedagogies, and the purpose of education and schooling.

The first area of contestation is the nature of STEM disciplines and, more broadly, the epistemic commitments of the disciplinary structuring of knowledge. As we discuss later, the amalgamation of disciplines into the category ‘STEM’ serves particular, political and economic agendas, and its epistemic validity is problematic. This becomes more so with addition of the arts in STEAM. The nature of science, both as a practice and a concept, is an area of contestation (Chalmers, 1987; Erduran and Dagher, 2014).

The analysis offered by Ziman (2000) includes at least five different schools of thought describing science: instrumental views; historical and methodological views, as well as sociological and psychological concerns, such as the role of science in society and psychological attributes, as might be found in curiosity, play and creativity of scientists. Critical appraisals of scientific practices are also signalling the increasing fragmentation and specialisation of scientific research, with scientists focussing on ever smaller areas of investigation. We note contestation over the deployment of technologies which can have very powerful impacts on the natural world with consequences that
are uncertain and often unknown. What is more, we recognise contestation over the way scientists, educators, and citizens in general ought to respond (see Funtowicz and Ravetz, 1993; also in relation to education Ravetz, 2006). In part, such contestation encompasses distinctions between different disciplinary approaches, including openness to interdisciplinary and transdisciplinary forms of inquiry, and draws attention to the need for a critical awareness of language as a powerful framing tool (see §2.5).

In the light of these areas of contestation, the approach taken by this review has not been to affirm a particular model or way of conceiving science in relation to education and schooling, but we have been concerned with questioning the perceived dominance of one model (see §2.5.1), to recognise the implications for the broader education of children, and to explore the implications of diversifying what constitutes science as a school subject and in learners’ experiences. In recognising a distinction between science and science education, we also recognise that science education ought plausibly to include a range of legitimate perspectives on science including, for example, axiological aspects and socio-political purposes of science.

This brings us to the second area of contestation which relates to the role of the arts and creativity in education. It is evident that society consumes and produces the creative products of arts and science practices: social media/Web 2.0, iTunes, television, and online games. In schools, arts-based and creative practices are evident in the teaching of a range of core subjects. However, recent work has called for recognition of the broader cultural value of the arts (Daykin et al, 2008; Crossick and Kaszynska, 2016). They argue that the role and potential of the arts-based approaches in education is neither fully documented nor fully recognised. One issue identified is the interchangeable use of terms such as ‘arts’, ‘art’, ‘arts-based’ and ‘creative’ in education without conceptual clarity (see §2.1). Thirdly, there are questions about the space curricula affords the arts to develop pupils more broadly. Claims are made for the ability of the arts and creative practice to foster ‘reflective’, ‘empathetic’ and ‘engaged citizens’, that can play a role in ‘peace-building’, ‘restoring mental health’ and ‘well-being’ (Crossick and Kaszynska, 2016, pp.7-8). The arts may also be engaged to ‘give citizens and students the qualities to deal with, operate and flourish in a fearful and uncertain global world’ (Parker 2013, p.60). Hence, the arts may have value beyond inducting pupils into the particular forms of the arts. However, a further substantial issue, integral to this report, is clarification of the pedagogical role of the arts and creativity in the teaching of specific subject areas, especially STEM – and the potential for the languages and sensibilities of the arts to be fully engaged.

Finally, the contested nature of science and art, and their educational imperatives is nested with a broader, contextual arena of dispute, the purpose of education and schooling. Both content and pedagogies are articulated through, and in the service of, differing political and ideological commitments, as well as different ontological and epistemic beliefs.

As the painter, who selects what is in the frame, what is not in, as well as how to represent it following the cultural expectations of their context (Berger, 1982), ideologies, political commitments, and beliefs shape schools and their role in selecting what can, and ought, to be known. These frameworks shape the views of all involved in educational practice, policy, and theorisation about education. They also shape the articulation of ideas. We note, as examples, some of the ways schooling can and is being framed:
• the politics of metrics and performativity measurements (see Kelly and Burrows, in Adkins and Lury, 2012; Ball, 2003) and more broadly, what Sahlberg (2012) has characterised as a ‘global educational reform movement.’
• The rise of ‘neoliberalism’, or the ‘economic model’ (see Oancea, Florence-Petour and Atkinson, 2015).
• The ways of privileging learning aesthetics, which ‘train the senses to conform to a predetermined field of the visible and the invisible’ (Lewis, 2012, p. 4), thereby disregarding the potential of the senses, and human creativity, to characterise engagement with other people, communities, and the natural world.

Further, we note frameworks stemming from interdisciplinary debates, across the sciences, arts, and humanities. For example:

• philosophical ideas, derived from different sciences, e.g. circular causality, emergence, non-linearity, holism, uncertainty, and ignorance (Harremoës, 2003; Mason, 2008), are used to inform curriculum and pedagogical practices.
• Recognition of interdisciplinary forms of inquiry, as they are developing within the growing field of ‘sustainability science’ (Westley, Scheffer and Folke, 2012) to inform scientific research and training of scientists;
• Integration and inclusion of non-academic, lay and folk perspectives (Funtowicz and Ravetz, 1993), supporting dialogical and experiential inquiry in the arts and the humanities (Parker, 2008).

An inquiry into STEAM as a hybrid pedagogical conception, arising at the intersection between sciences and arts will need to address fundamental questions about knowledge, values, and practices in education. While the review did not attempt to resolve inherently contested areas, it has: (i) reconsidered the role and purpose of STEM education in relation to the arts, creativity, and education more broadly; and (ii) appraised the distorting influence of economic and political priorities on the realities of children’s legal right to a ‘balanced and broadly-based curriculum’ (UNESCO, 2015). We have therefore sought to consider the claims made for, and about, creativity and the arts in relation to STEM subject areas. We make the common sense, and we believe widely agreed, assumption that creativity and the arts are important for wellbeing and have pedagogical utility. Teachers, and higher education STEM subject experts who were involved in the Extended Dialogues share this view. Whilst beyond our remit, we also recognise that this does not do justice to the claims, from within the arts and STEAM practitioners, of the importance of the arts and creativity for STEM education.

Part of our reflecting on contestation has highlighted that in the UK we are beginning to see a limited ‘natural experiment’, as different jurisdictions use devolved powers to explore different approaches to curriculum reform and the education of teachers. §1.2 provides a very brief review of different policy approaches to STEM education across the four nations. We outline key features below, setting the scene for the exploration of STEAM as a construct with potentially multiple configurations.
1.2 SHIFTING POLICY LANDSCAPE

Developments in the policy landscape across the UK display elements of convergence and singularity in relation to STEM education. We will give a brief introduction here.

In Scotland, we note three, key recent developments. The Curriculum for Excellence introduced in 2010, was designed to provide central guidance but also sufficient flexibility for schools and teachers to take account of local needs (Priestley and Humes, 2010). It listed four, broader capacities: successful learners, confident individuals, responsible citizens, and effective contributors, and eight curriculum areas: Expressive arts, Health and wellbeing, Languages (including Gaelic learners and modern languages), Mathematics, Religious and Moral education, Sciences, Social studies, Technologies. Social concerns were associated with ideas of citizenship, sustainability and outdoor learning accompanied by suggestions for interdisciplinarity and creativity. In December 2010, the Donaldson Review considered the full continuum of teacher education, emphasising the role of partnerships between Universities and schools, and teacher inquiry as a form of professional development (Donaldson, 2010, p.37). Most recently, the National Improvement Framework (NIF) reframed the focus on closing the attainment gap, particularly in literacy and numeracy; health and wellbeing; and employability. STEM is a priority area in NIF particularly with respect to raising “levels of STEM enthusiasm “and “connecting STEM learning in schools to the world of work.” Eleven new routes to teaching are expected to increase the number of STEM teachers. However, there is no explicit mention of interdisciplinary linkages with the arts.

In Wales, the ‘Successfully Futures’ Report (Donaldson, 2015) offers both a summary of the recent trends in Welsh education policy and sets out the future direction of curriculum reform. It structures its curricula proposal in terms of six ‘areas of learning and experience’. Specifically, in relation to this review, it identifies as two of the six: ‘expressive arts’ and ‘science and technology’. These areas are not to be seen as ‘watertight compartments’ or ‘timetabling devices’ (p.39). Rather it encourages teachers to ‘work creatively and collaboratively, across subject boundaries’ (p. 39). The report identifies examples of close links between the six different areas. In scoping the science and technology area it is noticeable that no links to the Expressive arts are identified. There is, however, a mention in scoping expressive arts which links ‘expressive arts….and the technologies components of science and technology’ (p. 44). Whilst the precise link is not developed, the natural reading of the example is that digital technologies may be useful in developing, recording, and transmitting expressive arts artefacts.

In Northern Ireland, a broad range of STEM focused strategies and initiatives was implemented since a review of STEM was commissioned by the Department of Education and the Department of Employment and Learning in June 2007 and published in 2009 (Northern Ireland Assembly STEM Briefing Paper, 2012). This review recognised that STEM had not been as high on the policy agenda as it had been in the rest of the UK and the Republic of Ireland. The aim of the review focused on the needs of the economy and the skills requirements of STEM graduates in the future projected workforce.

A mixed strategy for improving the uptake of STEM subjects in schools started to be enacted, detailed in Success through STEM (2011) and Success through STEM – One Year On (2012).
Recommendations focused in making STEM learning inquiry-focused; addressing disparity in STEM performance between schools; supporting broad based initiatives, such as, exhibitions; developing CPD programs for STEM teachers; greater emphasis on STEM careers and increasing the number of places for STEM in initial teacher education.

An Inspectorate Report in 2010 suggested that more needed to be done to support a new STEM framework for CPD for teachers (Education and Training Inspectorate, 2010). By then seventeen schools were designated as specialist schools in science, technology, and mathematics. New resource-based initiatives were enacted. For example, a ‘STEM truck’, a mobile laboratory and workshop purchased by the Department in 2009 made 250 visits to schools by 2012. The Department funded Sentinus a not for profit educational charity that received £400,000 annually to deliver a portfolio of STEM-based programs to schools.

In England, whilst the English education system retains a commitment to a broad and balanced curriculum, the expected achievement of pupils at the end of compulsory schooling skews this towards privileged subjects. The English Baccalaureate (E-Bacc) articulates a traditional hierarchy of subjects: positioning Maths as a double weighted subject and including Science (preferably as Biology, Chemistry, Physics) and Computer Science. However, it excludes Design Technology and any other Arts subjects. The Cultural Learning Alliance noted a consequent decline in take up of Arts subjects at GCSE, with Design Technology most significantly affected (CLA 2014). Reform of public examinations 16-18 has simultaneously emphasised greater conceptual challenge at a younger age with regards to content, and monitoring of regular progress in all subjects. The one practical impact in schools is a tighter focus upon disciplines.

Wider government or industry-led drives to support STEM or STEAM remain at a rhetorical level e.g. from the Culture, Media and Sport Committee (2013) and echoed by education and culture ministers. Industry led reports and programmes also promote education for young people in shortage STEM subjects (CBI 2014; Claxton et al., 2016, Wise, 2017). However, the Government has recently cut funding for its 45 STEMNET organisations, reducing it to an online teacher support role for coordinating STEM ambassadors. Although small in number, some variant secondary school models are enabling more inter-disciplinary STEM/STEAM-like education. Studio Schools and university technology colleges enable 14-19 year olds to acquire GCSEs through project-based learning, developed with industry partners.

In the Republic of Ireland, whilst the Irish education system retains a commitment to a broad and balanced curriculum, the expected achievement of pupils at the end of compulsory schooling skews this towards teaching to the test. Statistics are showing are showing access of over 80% in upper secondary school to higher education. The ‘Leaving Certificate’ articulates a traditional hierarchy of subjects: positioning Maths as a subject with bonus points and including Science (as Biology, Chemistry, and Physics). STEM education is very active at several levels, formally and informally with many initiatives; a broad-based strategy 2006-2013 and a dedicated Professor of STEM Education at a new EPI-STEM Research Centre at the University of Limerick. Government drives are reflected in the publication of a new STEM Strategy in November 2016 within an understanding that expertise in STEM disciplines and new policy and STEM teacher continuing professional development is ‘necessary to drive our economic ambitions, support innovation and provide the foundation for future prosperity’ (STEM education in the Irish School System, 2016).
However, since the economic crash of 2008, the Government has operated a policy of economic austerity and cut funding across the entire education sector; at the same time, there has been an unprecedented rate of publication of policy reforms by the Teaching Council and Department of Education and Skills and new modes of monitoring teachers in line with public accountability (Mooney Simmie, Moles & O’Grady, 2016). Curricular reform in lower secondary education emphasise greater freedom at school, and local flexible arrangements for teacher cooperation, resulting in industrial unrest with the largest teacher’s union to date, the Association of Secondary Teachers of Ireland (ASTI).

In summary, we note a surge of interest in STEM education across all nations. However, as a new term, STEAM does not appear to map directly onto the policy landscape. Some essential features may be potentially identified; e.g. interdisciplinary learning as indicated in Scotland and Wales, and partnership with external, not for profit agencies in the Republic of Ireland and Northern Ireland. Difficulties with tracing the policy-roots of the term are compounded by the growth of evidence-reports produced by industry patrons in the educational landscape (see for example Livingstone and Hope, 2011), and emerging STEAM-like practices in schools and outside schools, with examples across England, Australasia, and the USA.

That said, it is also noted that potentially competing narratives may impinge upon STEM as a policy priority. A concern for attainment and employability is expressed alongside more humanistic purposes such as equity and well-being. For example, in Scotland, critiques pointed to discrepancies between the civic purposes of the new curriculum and the use of assessment structures driven by metrics (Seith, quoting Humes, 2017). We note that Irish scholars expressed similar concerns in relation to the influence of policy on school curriculum and practices (Moonie-Simmies and Moles, 2014) which resonate with the views of educationalists across the UK. Hence the policy landscape is, at best, ambiguous about the potential for STEAM. As indicated in earlier section 1.1, such variety of approaches and views is unsurprising, nested as it is, within a complex landscape of multiple, changing and, unequal views. This review is a preliminary attempt to scope the field and to distil key elements to guide further research in relation to the principles, purposes, challenges and opportunities of STEM and STEAM education.

1.3 AIMS OF THE REVIEW

The review consisted of:

(a) a review of literature(s) and diverse practices concerned with how creativity, and ‘the arts’, are engaging with science, and technology, engineering, and mathematics, in education;
(b) exploratory dialogues with a diverse range of stakeholders, to elicit perspectives and orientations towards the term ‘STEAM’ and related pedagogies.

It sought to:

(c) identify potentially productive areas for further research and practice development. It took a broad and inclusive approach to creative pedagogies and involvement of the arts.
The review focussed on projects and practices which self-identified as ‘STEAM’ and related approaches that appeared to draw substantially on ‘the arts’ or creativity in pursuing STEM education; the so-called STEM to STEAM agenda.

It sought to uncover conceptions and relative perceptions of science and arts, and to illustrate the educational potential for pedagogical configurations which could inform further research in curriculum and pedagogy. We adopted a flexible and exploratory approach in order to move across different sets of concerns and different communities.

1.4 REVIEW APPROACH

In setting out the review we recognised that the word ‘STEAM’ can be used to achieve different purposes (rhetorically and logically) in different discourses. Further, we recognised that there was no shared understanding or shared conceptions associated with the word ‘STEAM’. Following Wittgenstein (1958) we, heuristically, assumed the significance of ‘language in use’, paying attention to the way stakeholders talk about STEAM within particular discourses and within a set of social and contextual relationships. Further, we were cognisant of the possible differences in concepts and conception of ‘STEAM’ which may be in play (see Recommendations §1 for a review of this difficulty). We designed the review to include a variety of opportunities for debate, sharing of perceptions, and dialogue amongst different individuals and organisations across the five nations.

We first met with a commission of established academics from different fields of research and educational inquiry, including science education, teacher education, gender studies, philosophy, anthropology, creativity and the arts. This first meeting held in Aberdeen enabled us to discuss the conduct of the review, and to identify fruitful avenues for further exploration. It thus provided guidance for planning the dialogues and reviewing the literature. The commission of academics was subsequently consulted during an online forum to get guidance on the themes emerging from the literature review and at the end, on the recommendations emerging from this report. Further to the first meeting in Aberdeen, academic members of the commission provided thematic inputs to the one-day events which were held respectively in Aberdeen, Cambridge, and Warwick. We will report on this in §3. The events were designed to offer many opportunities for discussion and dialogue amongst commission members and other invited speakers, sharing their knowledge, perspective, and experiences. Following limited response to an on-line survey designed to gather the views of teachers in Wales with regard to STEAM, a series of informal conversations were conducted with teachers and policy makers.

Sampling for membership of these groups was opportunistic, primarily through the contacts of the local organiser with some ‘snowballing’ through contacts of those initially invited. Membership was sufficiently diversified to include: teachers, local policy makers, external STEM and STEAM organisations, educational consultants and higher education academics in STEM subjects or education. As their biographies indicate, our gatherings included scholars and practitioners from a range of disciplinary and theoretical orientations, including: anthropology, archaeology, ethnic studies, gender studies, architecture and engineering studies, sociology, science education, philosophy, film studies, drama, and performance studies. We included graduate students and early career researchers working in cross-cutting areas of sustainability studies, creativity, and gender studies. Some participants had existing connections with one another and/or with the work of members of the core
team, while for most, the dialogues offered the opportunity to engage with one another for the first time. From these discussions, several themes emerged as having significance for our understanding and development of STEAM education related practices. Whilst no claim can be made that these ‘represent’ any group, the broad membership did allow for a range of perspectives to be heard.

Further informal discussions occurred with practitioners, policy makers, academic colleagues, and teachers about the emerging themes from these open discussions and their educational implications. These discussions recognised the devolved nature of education in the UK and the Republic of Ireland, including the emerging convergence of some aspects of curriculum and educational priorities across the five nations. Conversations also occurred with several overseas colleagues in Europe, Australasia, Asia, Scandinavia, South America, and the USA (see §4, and Appendix F for a full list of dissemination events). These helped to differentiate broader ‘global’ issues in science and STEM education and the arts, and the more local issues.

Funding from the British Educational Research Association (BERA) and support from the BERA Philosophy of Education and Creativity Special Interests Groups enabled the team to reach out to several interested people for attendance to the seminars and to cover much of the travel and accommodation costs. This support enabled all members of the core team to attend all seminars and for some of the speakers to attend also as invitees, and thus reinforce the dialogical approach of the review.

1.5 DIALOGUES EXTENDED IN TIME
During each meeting, core team members kept ongoing, often verbatim notes. Seminar speakers were recorded and powerpoints and audio-recordings were stored in a shared space and made available to participants on our website (https://steamresearch.wordpress.com). Photographs were used to document the events. Participants’ contributions, typically in small group discussions, were recorded on post-its, jotted notes, or flipcharts. After each dialogue, the team met to debrief the event. Drawing on the suggestions offered by Kamler and Thomson (2006), ‘themes’ were compiled with their corresponding ‘rheme’. In linguistics, while the ‘theme’ provides the focus of the sentence, the text or general conversation, the ‘rheme’ is the background set of complementary and/or diverging ideas which contribute meaning to the theme. In this report, the ‘theme-rheme’ document (see Appendix A) provided the running collection of points of agreement or disagreement amongst the core team and commission panel. By tracking the ‘rhemes’, we were able to keep and track a broad spectrum of ideas as they were being shared throughout the Extended Dialogues. The first account of emerging themes was compiled after the first meeting with the commission in Aberdeen. Subsequently, the document was regularly updated to provide a record of the ongoing reflections arising after each dialogue. Appendix A contains a working version of the ‘theme-rheme’ document. The document recorded some of the divergent and convergent nature of dialogues held with participants and amongst the core team over the extended period of the review. It informed the selection of some of the literature and some reflections emerging from the Extended Dialogues (see §3).

Albeit with limitations, the effort of the team was to strive for exploration of multiplicity, as we worked across very different domains of expertise. We worked in the digital space, using Skype for regular meetings, but we also inhabit different timescapes, as we met outside normal working hours and

1 These events were funded through external sources. Presentations were led by members of the core team on themes which addressed matters related to the STEAM debate.
while on our travels to conferences, family gatherings and holidays. Our meetings reflected the spirit of communication marked by excitement and tensions, as we inhabited a space of difference while working to get a shared task done.

1.6 REVIEW TENETS

Many questions arise when Science, Technology, Engineering, and Mathematics subjects (STEM) are interfacing with arts-based subjects and contexts (STEAM). Whilst, as we will note later in the literature review, the meaning of ‘STEAM’ is multi-vocal, multi-perspectival and complex, its emergence indicates a dissatisfaction amongst varied stakeholders of the content and manner of STEM education in schools. This dissatisfaction is engendered by at least five different themes, which provide the background narrative to the more sharply focused questions which directed this review.

Firstly, there is an argument that STEM education does not do justice, nor prepare pupils for engagement in, broader conceptions of STEM practice beyond the confines of the school. This critique comes in two forms. The first form is a challenge to STEM (and especially science’s) presumed claim to value neutrality. Discourses which reappraise the role and impact of STEM activity on the natural world (e.g. Colucci-Gray et al., 2013) call for the need to develop STEM education with a stronger critique of their embedded values. Such critiques espouse ‘pluralism’ as a necessary option in order to tackle situations in which stakes are high, knowledge is contested and there is a need to make decisions in conditions of uncertainty and ignorance. Pedagogically, this view argues that science education should aim at: a broader set of higher order cognitive skills, developing thinking creatively through different viewpoints; and an openness to dialogue which allows a multiplicity of ways of sensing, expressing and communicating (Lewis, 2011).

The second form is a concern that STEM education does not prepare pupils to engage in ‘wicked problems’ which require interdisciplinary and, perhaps, transdisciplinary capabilities (see Nicolescu, 2005). Thus, the critique offered of these two challenges is that STEM education needs to reflect on, and engage with these concerns, with the impact and value of these disciplines for society at large, beyond, that is, internal concerns for the STEM disciplines themselves.

Secondly, there is an argument, emerging from the scientific disciplines themselves, that STEM education has insufficiently kept up to date with the implications of scientific developments. These include, for example the ‘new physics’, especially quantum theory, general relativity, and its unification in string theory, and complexity perspectives in biology and neurosciences (see Hipkins, 2009). In biology, many of these debates stem from the recognition of the relational properties and inherent complexity and unpredictability of complex open systems. STEM education, in broadly perpetuating a 19th century, Western worldview, fails it is claimed to help pupils to address emerging questions in the philosophies and practices of STEM disciplines. These arguments emerge from mainstream scientific practice, reflecting a disjuncture between practice and educational experience, and from more marginal developments from practicing scientists, for example Bohm (1980) on implicate order, or Peat (1996), Craven (2015) and Grincheva (2013) on science within indigenous epistemologies. Thirdly, there is an ongoing and well-documented concern with the differential achievement in, and take up of, STEM subjects for different groups. Achievement in, and post-compulsory engagement with, STEM subjects show marked under-representation from certain groups (Murphy, 1997; Murphy and Whitelegg, 2006; Archer et al., 2014). Through the process of the review, we have engaged with correlations of underrepresentation with gender and socio-economic status (see Cambridge Extended

\[ \text{This was captured to some extent in AT17 (Science in Society) in the original National Curriculum} \]
Dialogue). Independently of the STEAM agenda, several arguments have been advanced as to the reasons for this effect and how this might be addressed. These arguments call for a reconsideration of the content and pedagogies of STEM education in schools, especially incorporating educational practices and approaches more prevalent in arts education, and hence link to themes in the STEAM literature.

Fourthly, there are arguments that STEM education is unimaginative in both curriculum and pedagogic terms. Although investigatory approaches have influenced practice, these have not dominated (see for example approaches developed by Woolnough and Alsop, 1985; Nuffield A-level Science, 1989). There appears to be, in STEM subjects, a longstanding assumption that the key aims of developing content knowledge are best achieved through ‘traditional’ classroom practices and simulacra of scientific experiments.

Finally, and more broadly, there are claims that the STEM disciplines themselves are epistemically foundational and exclude the possibility of different ‘ways of knowing’. Counterclaims draw attention to socially situated, social, virtue and indigenous epistemologies. These critiques are not only referring to Science and STEM, but they concern the enlightenment description of the epistemic landscape. Following this argument, some authors argue that STEM education is too committed to a model of western, rationalistic tradition of knowing and the justification of knowledge claims (Hyslop-Margison and Naseem, 2010).

All five challenges to STEM education are deemed, in the literature, amenable to at least partial resolution by the integration of some conception of ‘arts’ or ‘the arts’. These initial considerations from the literature, research and teaching experiences of the commission were distilled into three distinct, but interrelated questions to direct the review. These are:

An investigation into and consideration of:

1. the changing conceptualisation of science and arts, and the implications for science education.
2. The relationship between formal school science as it is currently taught and the differential access to science knowledge affecting groups inside and outside schools.
3. The potential of arts-based, creative pedagogies to foster inclusive, participatory, and interdisciplinary learning in science.

The three questions need to be understood in the context of a concern with STEAM education as an emerging, and as yet unclear, approach to STEM education.
This section presents diverse accounts of science, how these relate and interface with changes in education, and how this might enrich current debates around STEAM. We did not set out with the intention to undertake a comprehensive literature and its analysis. Our intention was, however, to give an account of relevant theoretical perspectives which may impinge upon, and contribute to, further understanding of STEAM discourses. We also aimed to add to the critique of STEAM education by including diverse perspectives from contemporary research and practice.

2.1 INTRODUCTION

Re-conceptualising school science has crucial implications for pedagogic practices and it is taken as the starting point for a review of current conceptions of education in Science, Technology, Engineering and Mathematics subjects (STEM) at the interface with arts-based subjects, pedagogies and contexts (STEAM).

As with STEM, the ‘A’ in STEAM is under-defined in the literature.

Differing conceptions and concerns are apparent and mere synthesis fails to capture these real differences in the application of the term. Nor does a focus only on literature utilising the term ‘STEAM’ capture emerging foci for research and practice: literature critical of STEM education and utilizing what others might identify as ‘arts’ approaches has also been included. It was thus apparent that for undertaking this review, conventional models and metaphors such as – ‘finding the knowledge gap’ – would not be sufficient; the field is contested and changing.

Hence, the literature review was conducted, and is presented, in two phases, drawing on two distinct approaches advocated by Oliver (2012), and developed through work by Moses and Knutsen (2012), and Moscovici and Doise (1994). The commission decided in Phase 1 to develop a ‘broad brush stroke’ mapping of the educational landscape in relation to STEAM. This, in part, reflected the desire not to focus just on particular ‘keywords’, but to consider theoretical themes, issues and to be inclusive of ‘grey’ literature. This review was framed by a series of key questions which provoked avenues of investigation (see Appendix D). The shaping metaphor was one of the bricoleur:

...at work and excited by his project. His first practical step is retrospective. He has to turn back to an already existent set made up of tools and materials, to consider or reconsider what it contains and, finally and above all, to engage in a sort of dialogue with it and, before choosing between them, to index the possible answers which the whole set can offer to his problem. (Levi Strauss, 1966, p. 12).

Phase 2 of the literature review reflected a more conventional keyword search of primary educational research databases. This phase searched on, and reviewed, literature on one of the STEM subject and at least one arts practice.
PHASE 1

Early searches revealed:

(a) the absence of a recognisable body of ‘STEAM education’ literature, and  
(b) that educational practice and research, which might be considered STEAM, was often not be framed or tagged as such.

It is recognised that what follows is neither an exhaustive nor an in-depth analysis of the literature. Rather, it is a useful first indication of where research and practice currently is in relation to the emergence of STEAM-like pedagogies. It does so by taking account of conceptions of science, the relationship between the arts and sciences in society, development in science education interfacing other disciplines. We begin with considering STEM before considering STEAM and proceed with prominent issues emerging from the composite set of literature.

2.2 ORIGINS OF STEM EDUCATION

The first use of the STEM acronym to mean Science, Technology, Engineering, and Mathematics, is attributed to the American National Science Foundation (NSF) in 1998, when it was used to denote their teacher education programme STEMTEC (Sireci et al., 2001). They included in ‘STEM’ a broad range of subjects, for example, social and behavioural sciences such as psychology. In the UK, ‘Set for Success’ (Treasury 2002) argued for the importance of the supply of people with STEM skills. The US Committee on Science, Engineering, and Public Policy report ‘Rising above the Gathering Storm’ (2007), argued for STEM in response to the poor performance of students in Science and Mathematics. It specifically linked future national prosperity with having enough STEM graduates to support the STEM workforce and, having enough STEM teachers to teach STEM subjects to the next generation (Wang, 2012). This link between STEM subjects, STEM skills development and future STEM jobs has been emphasised in a variety of reports culminating in the USA in the Obama-Biden plan of 2009 which, in part, involved a $250 million public-private initiative to recruit and train more STEM teachers. In the UK, the Department for Education (DfE) and Department for Business, Innovation, and Skills (BIS) developed and managed the Science and Innovation Investment Framework which looked at the effectiveness of government funding on STEM literacy and the STEM workforce. Further, there are significant, largely publicly funded, programmes of STEM Ambassadors and STEM CPD programmes for teachers developed through the National STEM Centre (now STEMNET; see Straw and MacLeod, 2015).

Despite the acronym gaining significant momentum across governments, countries and within business and education sectors (§1.2), there remains a significant lack of agreement on its definition, and the educational implications of STEM approaches across all four nations of the UK.

2.2.1 DEFINING STEM

Breiner et al. (2012) argue that there is no agreed, or even common, use of STEM. Many of the numerous stakeholders interpret it in different ways. Even within a Higher Education context, across both STEM and non-STEM disciplines, there was no agreed ‘operational definition or conceptualisation of STEM’ (Breiner, 2012, p. 6). The authors highlight that what it means to be
‘STEM literate’ differs among the key stakeholders. Within the general public the issue is starker; the Entertainment Industries Council found that when the public were asked what STEM education meant, 86% didn’t understand the term, and many confused it with STEM cell research. What is evident in both the history of the term, and its lack of a clear definition, is that STEM can be argued to have two interlinked perspectives. Firstly, it is an economic term identifying those subjects perceived to have greater economic importance, and secondly, it is an educational policy construct. This construct does not map directly onto the practices of schools, which remain committed to the individual disciplinary perspectives, nor does it map onto assessment frameworks. Whilst there is no doubt in the literature that a rhetorical link between the two perspectives, economic and educational, exist, such links appear to be only loosely defined.

2.2.2 STEM EDUCATION

While the economic argument for STEM is driven by objective outcomes, such as numbers of students taking STEM degree programmes or entering STEM related careers, the educational construct of STEM is less easy to characterise. Further, we would tentatively suggest that accounts of STEM education are dependent in part on the broader educational and curricula philosophy, policy, and practice. In particular, we note the impact of both national education systems and within individual schools. As a result, the applicability of STEM education research conducted in other countries (such as Breiner et al., 2012), needs to be treated with caution when applied to the UK. In general, however, STEM education seems to imply one or more of three elements:

- A recognition that STEM professionals integrate STEM knowledge and skills rather than compartmentalizing them into the individual disciplines. Therefore, STEM pedagogies seek to break down traditional subject silos akin to what STEM careers require (Breimer et al., 2012; Wang, 2012).
- A more inquiry and project based way of learning which promotes real life problem solving through deep learning experiences (Breiner et al. 2012; Isabelle and Valle, 2015).
- The integration of STEM in social and educational contexts which make connections between schools, communities, and global enterprises (Wang, 2012).

Each element requires re-consideration of ideas of knowledge, and substantial reconfiguration of curricula and practices.

2.2.3 CHALLENGES FOR STEM EDUCATION

Yakman (2010) argues that, within the educational context, there are two different interpretations of STEM. Firstly, as a curriculum construct of four subject silos which can reinforce segmented disciplinary knowledge but are given a hierarchically important position within educational policy and practice. Secondly, STEM as an integrative, cross-curricular approach which at least partially transcends disciplinary silos. Wang (2012) argues that a fundamental criticism of STEM is that there is no consensus on how to integrate the subjects effectively. Isabelle and Valle (2015) state that it is common within education:

...that the four disciplines that make up STEM are viewed as separate domains of knowledge, tied together mainly for the role they play in the job market of the 21st century global world. (Isabelle and Valle, 2015, p. 2)
This criticism is also recognised by Khan, former CEO of the British Science Association (BSA), who recommends an end to such segregation and argues:

> In an age of inter-disciplinarity, studying physics, biology, and chemistry as supposedly separate subjects could be seen as an anachronism even for those going on to become scientists. But it’s perhaps even less helpful for those who we simply want to be members of a scientifically literate society; might a better route be having young people look at the science of, say, climate change, alongside its historical, geographic, and political elements? (Khan, 2015.)

So, even a decade after STEM became a prominent acronym within the policy arena, there remain substantial difficulties in translating the concept of STEM education, from curriculum design to macro-curriculum policy. This has been emphasised through educational reforms since 1988 (in England and Wales) where learning has been further framed through separate subject disciplines, focused upon subject knowledge. Further, Breiner et al. recognise that there is some evidence that despite the intended inquiry learning, ‘instructional strategies in the typical classroom have not changed’ (Breiner et al., 2012, p. 5).

Alongside these challenges for STEM education, there is some evidence that educational issues are having an effect on economic discourses. Echoing the longitudinal qualitative ASPIRES project (2013), the Project STEM: Book of insights (2014) undertaken by the Department for Business Innovation and Skills (BIS), looked at perceptions of STEM subjects among young people. Both the ASPIRES and BIS reports found that young people thought STEM subjects are difficult and that choosing them could lead to failure. They also found that young people thought that STEM subjects lacked creativity and did not relate to the images or aspirations they had of themselves. The reports argued that these factors negatively affected young people’s choice of STEM examination courses.

In addition, whilst HEFCE research shows that undergraduate numbers in STEM subjects have increased since 2006, the Confederation of British Industry (CBI) still reports 39% of firms had difficulty recruiting to posts needing STEM skills and knowledge. Employers report that the STEM qualified applicants they see are neither sufficiently rounded, grounded, nor ‘work ready’ with a third dissatisfied with school leavers’ problem solving skill (CLA, 2014).

In fact, the STEM to STEAM report by the Cultural Learning Alliance (2014) goes a step further stating that there is a general view of a crisis in education in the STEM subjects in schools. They argue that deep, sustained, varied learning is key to STEM education and that this requires a rethinking about education more generally.

### 2.3 THE ORIGINS OF STEAM

The rise of the term STEAM to denote Science, Technology, Engineering, Arts and Mathematics is attributed to a National Science Foundation symposium on the relationship between arts, STEM learning and workforce development in 2007 (CLA, 2014). The NextGen report (Livingstone and Hope, 2011) and Creative Industries Federation’s Creative Education Agenda reports (CIF 2015) argued for the Arts to be at the heart of education, in order to develop and nurture innovation. It was this shift within the economic argument for STEM to become STEAM that saw the acronym gaining
The government was urged to resist ‘the narrow view that science, technology, engineering and mathematics represent the exclusive route to economic successes’. Instead, ‘students...must be able to access the widest possible programme of creative subjects to prepare them to play a part in the knowledge economy’ (Universities UK, 2012; see also CIF, 2015, p. 9). Further, the final Culture, Media and Sport Select Committee Report stated that ‘[t]he crucial role of arts subjects in a modern education should be recognised, and arts subjects should be added to the STEM subjects, changing STEM to STEAM’ (DCMS, 2013, para. 117).

Several publications advance a different narrative, asking not how STEAM emerges as an aggregation of STEM and the arts, but at what stage the STEM and arts subjects were disaggregated. They argue that a culture of invention and ingenuity, which typically results in economic advantage, is dependent on the development of polymaths through schooling. They cite examples as diverse as Steve Jobs, Leonardo DaVinci, Galileo and Einstein, indicating a long history of interconnectivity between the sciences and arts. (CLA, 2014; CIF 2015, BSA 2015; Hayes, 2015).

Nobel laureates in the sciences are seventeen times more likely than the average scientist to be a painter, twelve times as likely to be a poet, and four times as likely to be a musician. (Pomeroy, 2012, cited in CIF, 2015)

**2.3.1 THE AIMS OF STEAM**

The CLA put forward three interlinked arguments as to why a return to STEAM is necessary; STEAM for education, STEAM for employment, and STEAM for the economy (CLA, 2015). Firstly, it argues that STEAM has the potential to improve the general attainment of young people. Citing evidence that the arts improve cognitive scores, including in maths and literacy, they suggest that STEAM has the potential to improve PISA rankings with the inclusion of a problem-solving element, alongside English, Maths and Science (CLA, 2015).

Secondly, they suggest STEAM has the possibility to increase innovation. As noted above, they also add that Nobel Laureates in the sciences are likely to be more actively engaged in the arts and suggest that studying both is more likely to lead to innovation. The argument is supported by the Warwick Commission Report (2015), which reminds us that an English education system that is not multi-disciplinary, and infused with creativity and enterprise: “[w]ill negatively impact not just on the future of the creative industries, but also on our capacity to produce creative, world-leading scientists, engineers and technologists” (Warwick Commission Report, 2015, p. 15).

Thirdly, the argument for employment sees STEAM as a motivator and engager of young people into STEM subjects and careers. They argue that it develops well-rounded individuals, who are ultimately more employable. The arts, they argue, can enhance high performance teamwork, change management, intercultural communication, improve observational skills and improve adaptability. Further, they state that ‘the humanities’, including the Arts, provide ‘an intellectual framework and context for thriving in, and understanding, a changing world’ (CLA, 2015, p. 11).

Ultimately, all three arguments can be seen to provide weight to the economic imperative for STEAM, as a mechanism for improving competitiveness when linked to increased innovation, improved labour market outcomes and GDP.
2.3.2 DEFINING STEAM

STEAM, as we have noted inherits the difficulties of defining STEM, with the added complication of a lack of clarity related to the meaning and role of the ‘A’. In §2.4.3 we will discuss the possible ways in which work in the arts may illuminate this difficulty and, in §2.12, we discuss the potential contribution of ‘creative pedagogies’. Yakman (2010) echoes our own finding that in the STEM/STEAM literature there is no credible definition of the arts or arts education. Yakman seeks to provide a taxonomy of the arts – a broad account including humanities as well as arts disciplines and practices, but it has limitations, and its usefulness is therefore unclear (see §2.4.3). Yakman’s concluding view is that the ‘A’ denotes ‘all not already included in STEM’.

Yakman does focus on the idea of the ‘A’ as promoting connection, and this is picked up elsewhere (see CLA, 2014; SteamCo, 2014). However, there are different accounts of what is to be connected: science and society (Yakman), people (SteamCo), or making real world connections between school subjects (CLA). For Maeda (CLA, 2014), it is the connection between STEM and other ideas that creates the conditions for innovation:

*Innovation happens when convergent thinkers…. combine forces with divergent thinkers – those who professionally wander, who are comfortable with being uncomfortable and who look for what is real.* (CLA, 2014, p. 4)

Other writers emphasise the importance of connection with the self (Blair, 2014), with the biosphere (see Ingold, 2014; Van Boeckel, 2015). Yet, this conception does not seem to resonate or align with what other authors seek to achieve through the addition of the ‘A’, for example, a means of humanising science and technology (CLA, 2015), or as a site for developing technological expertise (see Chung, 2007), or as an economic necessity:

*There is strong evidence showing that employers across our leading industries need recruits with arts and creative skills, knowledge and understanding – people who can visualise, empathise and communicate, ask questions, experiment, create and perform. As Eric Schmidt, Executive Chairman of Google, said…. the UK desperately needs polymaths.* (CLA, 2015)

Defining STEAM therefore reflects an articulation of what is absent from, or problematic with, any particular author’s conception of STEM education rather than a positive ascription of a subject domain or pedagogical approach. Further, in our consideration of the literature on STEAM and STEAM-like education, there does not appear to be an emerging taxonomy of differing, but related conceptions of the ‘A’.

2.4 CONTROVERSY AND CRITIQUE

The literature presented above sets out the emerging, often complex, use of the terms STEM and STEAM which have gained significant currency in terms of both policy and practice. On balance, STEAM is a site of change and possibly, of ‘resistance’, concerned to adapt, modify, and develop political and ideologically informed accounts of STEM education. As such, it is a portmanteau term, and one which both contains the difficulties inherent in STEM, as well as introducing some unique to
itself. Further, the term is used in different ways by different authors (to draw on Wittgenstein's, 1958, arguments of 'meaning is use'), and cannot be fully detached from the real discourses of which it is part. Whilst making no claim to being exhaustive, three uses of the term are evident: as supporting creative pedagogies; reflecting diversification of what counts as 'science'; and a resistance to technicist and economically focussed accounts of education.

In the following five subsections, we consider and discuss a number of issues emerging in the STEAM literature. It is worth noting two points. The first is that we have not tried to contextualise these issues in wider educational debates. STEAM as a site of resistance is not just concerned with STEM disciplines, but an extensive review of educational philosophies, policies and practices that is well beyond the scope of this review. We recognise, and expect, that others will see, that these issues are illustrative instances of more general issues. For example, concern about the narrow nature of STEM education reflects Ryan’s (1999) critique of liberal education, and questions of epistemology reflect, amongst others, Hetherington’s (2011) recent development of practicalist epistemology, and Chappell’s (2012) account of objectual knowledge, more generally. The second is that the review is directed by those writing in the area of STEAM and their specific concerns. We make no comment on the validity of the arguments made, nor their justification in broader empirical and philosophical literature. The work reviewed does not, as far as we can see, offer a systematic consideration of the domain, but reflects a range of political, ideological, and educational concerns.

2.4.1 SUBJECT SILOS
STEAM inherits the tensions between S-T-E-M as four separate subjects, and their reconceptualisation as STEM through interdisciplinary connections and learning. There are some discussions on the relationships between different disciplines (see §2.4.2 below), but there remains little theorizing about the way in which the Arts and STEM can effectively work together to achieve the expected educational and economic outcomes.

Educationally, we note here both historic and contemporary differences across the four nations. The English system has a long history of favouring disciplinary specialism (Snow, 1959), differing from that in Scotland, particularly with an educational system more reflective of those in continental Europe (Anderson, 1995).

2.4.2 POLICY CONTEXT
In practice, there remains a lack of pupils in English schools undertaking a broad range of arts and science subjects, and examination systems tend to undermine any attempts to promote this (see University of Warwick Commission, 2015; CLA, 2014). Whilst there are differences, the policy implications are also reflected in Wales, Northern Ireland, and Scotland. NESTA argues that ‘governments should remove the perverse incentives that currently riddle secondary education, deterring young people from combining arts and science subjects’ (NESTA, 2014). They argue that performance tables used to rank schools in England, Wales and Northern Ireland are still overtly reliant on metrics that prioritise the sciences over the arts.

This is codified, in England, in the exclusion of Arts subjects from the English Baccalaureate (EBacc) qualifications framework and the Key Stage 5 list of ‘facilitating subjects’ and reinforced in the 2016 Progress 8 directive. A survey by the National Society for Education in Art and Design showed
Reviewing the potential and challenges of developing STEAM education through creative pedagogies for 21st learning: how can school curricula be broadened towards a more responsive, dynamic, and inclusive form of education?

that more than a third of teachers had less time to teach art and design over the past 5 years, with 93% pointing to the EBacc as a major contributing factor (NSEAD, 2015). Conversely, the Warwick Commission argued that if we focus on the EBacc subjects in isolation, we lose the possibilities produced by a creative ecosystem, which equips young people from every background with the skills to think beyond boundaries (University of Warwick Commission, 2015). However, as was recognised by those attending the ‘STEAMHACK’ event led by the CLA, practically:

...schools, rigid assessment structures and curriculum imperatives combine with heavy work-loads to squeeze out time to breathe, collaborate or innovate. The pressure doesn’t just come internally from the system: parents and students want their children to succeed and there are no clear messages presented to them about the value of cross-disciplinary teaching and learning. (CLA, 2015)

2.4.3 DEFINITIONAL PROBLEMS WITH ‘THE ARTS’ OR A

As suggested in §2.3.2, the conception/s of the arts signified by the A in STEAM is unclear across the literature. It may be used interchangeably to denote ‘the arts’, (visual) art, another art form e.g. drama, music or dance, or pedagogies dominant in arts classrooms. The associated values of such a range of options may be rooted in well-being, aesthetics, economics, humanitarian issues and / or education.

Despite this apparently diverse range of conceptions, the STEAM literature tends to affirm a common view of the arts as an important part of a broad and balanced curriculum. It, also views the arts as having a distinctive contribution to make to STEM education.

The STEAM literature echoes a view of the arts as valuable both intrinsically and instrumentally; the arts are deemed to be social, inclusive, humanising, and thereby significant for human development in society (Belfiore and Bennett 2007; Canatella 2015). Arts education literature proposes that engagement with the arts in education matters in young people’s development (Robinson, 1982, Best, 1992, Trowsdale, 2015). Specifically, in STEAM education, the arts intrinsically bring a roundedness to the educational experience of pupils in which they can connect different aspects of their own and other human experience and practice (University of Warwick, 2015; Livingstone and Hope, 2011; Trowsdale, 2016). As such, it is argued that the arts retain their legitimacy as specific and equally valuable perspectives on the world. Instrumentally, literature also talks of the arts as valuable in that they support pupils’ learning, and motivation to pursue learning, in areas such as STEM subjects. Thus, there are indicators that the addition of the ‘A’ signals more creative pedagogies (see §2.4.4 below; Sefton-Green et al., 2011), thereby giving pupils a more positive view of the STEM subjects, continued engagement, and involvement beyond post-compulsory education.

Case studies, which largely characterise the use of arts in STEM education, tend to engage with particular forms of arts practice. Perhaps in recognition of this, Yakman (2010) suggested her taxonomy of ‘five interlinking types’ of arts (Language, Fine, Physical, Manual, and Liberal). Her intention appears to be to characterise how an arts practice might be used in education, but the distinctions are not always helpful. For example, in physical theatre practice there is, necessarily, a significant over layering of, at least, the ‘language’, ‘physical’, ‘manual’ and ‘liberal’ dimensions. The variety of practices therefore challenges the usefulness of these distinctions for STEAM. The taxonomy also appears to exclude dimensions such as the affective, sensuous, and embodied
dimensions of learning. Many have argued that these aspects indeed underpin the appeal of the arts in education: where ‘the active side precedes the passive’ (Dewey 1897), and indeed physicality and associated feelings shape thinking (Claxton, Lucas and Webster, 2010; Fuchs and Koch, 2014; Kontra et al., 2015; Stolz 2015; Wilson, 2002).

Another factor relevant to how the arts feature in STEAM relates to the hierarchy of the arts, borne of the history and their perceived differential value to schools. Art, introduced into English public and grammar schools in the nineteenth/early twentieth century, remains a rare, discrete arts subject in the UK nations’ National Curricula. Consider, for example, its position in England since 1988 (Gillard, 2011). It also, therefore, unsurprisingly appears most frequently in the STEAM literature. In contrast drama, which has long advanced its role as ‘a learning medium’ (Wagner, 1974), is less apparent in STEAM research literature, although surfacing in science education literature (see §2.7), and evident in accounts of STEAM practice (see §3).

2.4.4 TENSIONS ON THE MULTIPLE PURPOSES OF STEM EDUCATION

Interwoven in the debates on the precise meaning of the ‘A’ in STEAM, is a broader concern with the potentially diverging purposes of science education. These are generally recognised as pertaining to two main sets of concerns: education of STEM specialists, and education that includes the broader, ethical, and intellectual development of children, as persons and citizens. These concerns lead to different curriculum designs and pedagogies (Layton, 1972; Dillon, 2009; Day and Bryce, 2013). As Rudolph argues ‘[a] science education for individual moral and intellectual growth—the goals we have always sought for developing citizens—looks (and should look) different from a science education for technical competency and disciplinary expertise’ (Rudolph, 2015, p. 1075).

There is a tension in the literature between accounts of STEAM which foreground a commitment to a more humanizing education linking science and society (as indicated earlier, see CLA, 2014), and those who emphasise the value of STEAM to excite and motivate pupils as scientists.

2.4.5 THE CHANGING CONTRACT BETWEEN SCIENCE AND SOCIETY

There is a broad socio-political concern with, some might say crisis in, the relationship between people and their environment. Such crisis finds its roots in culturally seated ideas of Nature which have given rise to enlightenment epistemologies (see, for example, Bateson, 1974; Van Boeckel, 2015). In fact, for a number of authors this perceived ‘crisis’ stimulates their critique of dominant conceptions of STEM education. They argue this debate exemplifies the complex and challenging relationship that science has with society, and the need for science to change in order to meet the challenges that lie ahead. As Raven states:

_We need new ways of thinking about our place in the world and the ways in which we relate to natural systems in order to be able to develop a sustainable world for our children and grandchildren._ (Raven, 2002, pp. 239-40)

Whilst, Lubchenco argues, science has developed new and lucrative means for economic sustainability and growth, and led to a vast range of useful discoveries, she notes this may not best serve the needs of society to meet future challenges (Lubchenco, 1998). This argument arises from two interconnected concerns about the nature of the global problems facing the world. Firstly, that scientific and
technological developments have provided new opportunities, but it is also important to recognise that such developments have also provided the means by which humans have impacted significantly on Earth (Gray and Colucci-Gray, 2014; UNEP 2001). As Gray and Colucci-Gray (2014) state:

*While these global issues provide a focus for the attention of science and politicians looking for ‘solutions’, another side of the coin is the fact that the increasing scale and power of science and technology, coupled with huge financial investment, has actually contributed to many of these problems.* (p. 20)

Secondly, the nature of the problems at hand which, as Bammer (2013) argues, are new, are developing and situated at a global scale. These wicked problems pose significant challenges to what Jasanoff (2002) calls traditional scientific approaches, by exposing the inherent difficulties of a simplistic, reductionist view of science and technology.

### 2.5 THE EPISTEMOLOGY AND ONTOLOGICAL ASSUMPTIONS OF STEM/STEAM

It is worth at this point reiterating that this review reflects the interests and concerns of those presently writing in STEAM education. Epistemology and ontology are contested spaces, whose very questions are themselves multi-vocal. We are not concerned with epistemic and ontological issues per se, but with the epistemological and ontological challenges the STEAM literature identifies, and those that emerge from the particular challenges of considering STEM in the light of the arts. A key element is the justification for disciplinary thinking, and particularly the strong distinctions between the disciplines. Further, a particularly evident difficulty is the lack of cumulative literature and ongoing critical debate in the STEAM field, nor is there detailed engagement with, or grounding in, the more technical philosophical literature.

As a result, we set out the issues in a series of subsections, recognising however that many of the issues are interrelated, and that they often relate to issues identified earlier.

#### 2.5.1 BEYOND MONO-DISCIPLINARITY

A number of authors have identified significant criticisms of the disciplinary structure of STEM subjects within education (for example, Erduran 2014, 2015; Llewellyn Smith, 2011; Hughes and Lury, 2013; Trauth-Nare 2015). These criticisms include:

- The practical ineffectiveness of ‘monodisciplinary sciences’ in approaching contemporary problems (see Llewellyn Smith, 2011; Erduran, 2014).
- A critique of the perceived claims to neutrality, emphasis on reductionist conceptions of reality(ies) and experimental methodologies that remove knowledge production from contexts (see Colucci-Gray and Camino, 2014; Erduran, 2014).
- The dominance of an objectivity/subjectivity dichotomy where scientific fact is separated from subjective interpretation (Erduran, 2014).
- The idea of universality and a foundational ‘one science’ which claims that ‘fundamental knowledge leads to development’ (Colucci-Gray et al., 2013; Vidal and Simmoneaux, 2013; Krug and Shaw, 2016).

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3It is worth noting that there is a predominance of work within a phenomenological tradition.
Ingold’s (2013) discussion of the dominant role of the hylo-morphic model (where form is imposed and matter is passive and inert) is consistent with this view of STEM knowledge, where nature and culture, learner and subject, cognitive and sensory, knowledge and action are disassociated. These concerns reflect Dewey’s pragmatism with its rejection of either/or in favour of both/and; though Carr (2016), has recently presented a sustained critique of Dewey’s position, arguing that in relation to a range of specific distinctions (e.g. body/mind), such rejections are incoherent. Carr’s criticism would seem also to question Ingold’s position.

These critiques have force in two directions. The first, is in questioning the legitimacy of our present conceptualisation of the discipline(s) of science. The second is to direct attention to the need to move beyond ‘monodisciplinary’ approaches to STEM education. Where the first is evident in the literature, it tends to be in support of a humanising of STEM education, through and by the arts (the mechanisms being unclear), which supports a critique of neo-liberalism and concern for sustainability issues. This is often categorised in terms of ‘post-human’ or ‘post-normal’ science (Quinn, 2013). The second reflects both pragmatic and epistemic discussions on multi-, inter- and trans-disciplinary working. We will address each briefly.

### 2.5.2 POST-HUMANIST AND POST-NORMAL EPISTEMOLOGIES

Several authors argue for an epistemology in which we move away from humans as being at the apex of knowledge (Quinn, 2013; Hughes and Lury, 2013; Ingold, 2010, 2013; Taylor and Ivinson, 2013; Colucci-Gray and Camino, 2014). Quinn summarises the idea of a post-human epistemology as ‘not what distinguishes me from all that is around me and makes me superior to it, but what makes me part of it’ (Quinn, 2013, p. 742). It is this ‘being’, ‘becoming’ and the mutual implications of ‘knowing and being’ or, put another way, learning with and from, rather than about (Quinn, 2013), which provides a way into considering how arts epistemology and practices may provide a useful perspective on how the ‘A’ in STEAM could be harnessed effectively to reframe STEM. The pedagogies predominantly used in the arts appear to offer opportunity to develop knowledge in relation to and with others, harnessing different ways of experiencing the world, which emphasise the emotional, sensorial, intuitive, and empathetic, and thus would provide support to this view.

Barad (2007) advances a complex view of ‘the role of human and nonhuman, material and discursive, and natural and cultural factors in scientific and other social-material practice’ (2007, p. 26). In doing so, she points to the inextricable interconnection between epistemology, ontology, and ethics, thus advancing a primarily ethical concern, both in research and practice. From this perspective, we may see a central ethical concern for STEAM education. Further, Papadopoulos (2010, p.194) extends the post-normal conception of ‘multiplicity of legitimate perspectives’ beyond anthropocentric frames and approaches: “post-humanism refers to the complex socio-material constellations in which certain human, non-human others and the biosphere participate equally but differently in the creation of alternative environments of existence”. Such theorisations bring together the importance of marginalised experiences with broader concerns for sustainability.

### 2.5.3 MULTI-, INTER- AND TRANS-DISCIPLINARY STEM

As Yakman (2010) argues, STEAM can be considered as an integrative approach which either seeks to draw together different disciplinary perspectives, or in the case of trans-disciplinarity to transcend them. Generally, the argument is practical (see Llewellyn Smith, 2011; Erduran, 2014) in which monodisciplinary approaches are ineffective in addressing contemporary problems. The
educational implications for individual pupils are less clear. The practical argument directly implies that STEM specialists need to work in multi- and interdisciplinary teams, but what this means for their understanding and ability in disciplines other than their specialism is unclear (Mooney Simmie and Lang, 2012). Compulsory schooling tends to give rise to pupils who have been inducted into a range of disciplinary forms, though not necessarily into ways of seeing the connections between these different disciplines. As we have noted earlier, in the UK Key Stage 5 has clear disciplinary specificity, but we found no literature specifically exploring the implications of the need for integrative approaches with this group (exceptions are the support documents for the few A-levels in Science, e.g. AQA course in Applied Science).

Transdisciplinary approaches, emerging largely from scientists’ dissatisfaction with their disciplinary limits, require a more radical position, though one which has a similar concern with practical, complex problems and solutions:

_Transdisciplinarity complements disciplinary approaches. It occasions the emergence of new data and new interactions from out of the encounter between disciplines. It offers us a new vision of nature and reality. Transdisciplinarity does not strive for mastery of several disciplines but aims to open all disciplines to that which they share and to that which lies beyond them._ (First World Congress of Transdisciplinarity, 1994, Article 3)

In transdisciplinary approaches, unlike disciplinary based work, there are no ready answers to questions as to how one validates knowledge. Unlike interdisciplinary and multidisciplinary work, transdisciplinary scholarship does not seek a resolution by using the conventions of one discipline. In a review of her own approach to transdisciplinary work, Morgan notes that:

_“My operating style is to incorporate reliable sources of knowledge from any source, as it bears on the point I am trying to make”. (Morgan, 2000, p. 39)_

The image is one of stitching together ‘facts’ about the world each of which is validated in its own disciplinary home. Although the literature does indicate the potential for trans-disciplinarity, there is little discussion of the precise educational implications. There are indications that what is really at question is the epistemic mapping of the disciplines, but this is not clear in the literature. The link to art/the arts is also unclear in the literature. The literature review of creative pedagogies (§2.12), will contribute further dimensions to opportunities for curriculum integration (see Barrett et al, 2015).

### 2.5.4 Epistemology in the Arts and STEAM

‘The Arts’ may be a problematic label, and the ‘A’ of STEAM may be interpreted and used in a wide range of arguments which promote different conceptualisations of their role in relation to STEM learning (Gadsen, 2008). There are, however, themes which suggest how ways of knowing and learning in the arts support a desirable change in perceptions of STEM knowledge. Van Boeckel (2015) echoes a non-western view of the arts in recognising a difficulty with the usage of terms such as Art, Artist, Artwork and what can be learned from them. He argues we need to:

_...sever the notion [of the arts] from the nouns ‘artist’ and ‘artwork’ and instead shift our attention to the act of creating and releasing something new and meaningful into the world._ (Van Boeckel, 2015, p. 115)
Focusing on the act, the doing, the making and creating, provides a challenging re-visioning of STEM, which moves away from description of the world to experiences of being in the world, from focusing on products of knowledge to the process of knowing, from consuming knowledge to actively making and co-producing knowledge.

2.5.5 KNOWLEDGE IS CONTEXTUAL

Unsurprisingly, the idea of local, contextual, situated knowledges runs through many of the articles reviewed (Ingold 2010, 2013; Zoller, 2013; Ivinson and Murphy, 2003; Quinn, 2013; Hughes and Lury, 2013; Hodson, 2014, Blades and Newbury, 2014; Trauth-Nare, 2015). This challenges the idea of knowledge as (only) objective, universal and neutral, with Evagorou et al (2015), arguing that it enables us to move away from knowledge as being ‘inside scientists’ minds to ‘practices that are cultural and deeply contextualized within fields of science.’ (Evagorou et al, 2015, p. 10). Colucci-Gray and Camino (2014) argue that narratives developed through local knowledge can bring criticality to scientific assumptions, broadening communicative tools and welcoming novel ideas and issues. ‘Lokavidya’, a term which signifies everyday life as the centre of knowledge production (Colucci-Gray and Camino, 2014), and ‘landscaping’ (see Wylie in Quinn, 2013) share a view of epistemology which is practical, reflectively dynamic, responsive, and adaptive to the conditions in which knowledge is created.

At the core of this theme are ideas of materiality, which several authors either explicitly discuss or touch on. These include materials as active (Hughes and Lury, 2013; Ivinson and Taylor, 2013) and matter as vibrant, directly challenging an objective, universal, de-contextualised epistemology. Ingold argues that ‘to observe a thing is not to be locked out but to be invited into the gathering’ (Ingold, 2010, p. 4). In this way knowledge emerges as part of the complex meshwork of interacting threads which are gathered in a situation, and therefore gives rise to the argument that knowledge is local, or situated, where different types of materiality intra-act (Hughes and Lury, 2013). Local issues have a more direct impact on people, as indicated by Latour (2004), in relation to the shift from matters of fact to matters of concern.

2.5.6 KNOWLEDGE IS LINKED TO ENVIRONMENT

The problematic conception of the relationship between humans and their environment is longstanding. As Overstrom puts it:

Human progress has historically been measured by our ability to rise above the influence of nature, and economic security by the rate at which natural resources could be transformed into.... products. (Overstrom, 2013, p. 207)

It is against this backdrop that authors, see Barbiero (2011) and Speth and Kellets (2013), argue that current and future socio-scientific issues ‘cannot be solved through science, government or economics alone…. quality of human existence depends on our ongoing experience and connection to the natural world’ (in Overstrom, 2013, p. 207).

To address this need to connect young people to their natural world, a number of authors have argued for ‘real world’, immersive approaches (Zoller, 2013; Hodson 2014; Berto, Pasini and Barbiero, 2015). Braidotti suggests that post-human thought can be seen as ‘a philosophy of the outside,
open spaces and embodied enactments’ (Braidotti in Quinn, 2013, p. 739). Quinn develops this point further, by arguing for a need to ‘increase our attentiveness to things, artefacts and spaces in schools that are often overlooked in favour of the social or interpersonal relations’ (Quinn, 2013, p. 740). In this sense, Quinn argues for a critical awareness of the role of nature as an integral element of post-humanism. She concludes by asking the question, ‘[h]ow is nature in the classroom as well as outdoors?’ (Quinn, 2013, p. 752).

Van Boeckel supports this focus on nature drawing on Bateson (1974) to explain that instead of relating to nature by analysing small atomised features, we need to ‘live in’ the patterns and relationships between these. He goes on to argue that the arts could provide an opportunity to explore such patterns (Van Boeckel, 2015, p. 112). As an example, Van Boeckel suggests using arts as a starting point for ‘living in’ nature, and terms this Arts-based Environmental Education. He argues for ‘receptiveness to sense perceptions and observations’, using ‘artistic methods to express personal environmental experiences and thoughts’ (Van Boeckel, 2015, p. 113). Overstrom (2013) uses the metaphor ecotone (literally used to mean the edge effect in ecology, where two different habitat types or communities meet, and species thrive by accessing both) to explain the potential of physically bringing together art, science and research. Such ideas align very well with Goethean science (Bortoft, 1996; Reason & Goodwin, 1999; Seamon, 2005) now being revisited as an appropriate approach to science for our current ecological crisis. The Goethean approach to science according to Holdrege, (2005) “involves heightened methodological awareness and sensitivity to the way we engage in the phenomenal world”.

Direct experiential contact coupled with prolonged, attentive efforts to look and see became the basis for descriptive generalization and synthetic understanding” (Holdrege, 2005, pp. 86-87). Thus, there is as much, if not more, importance attached to how we experience the phenomenal world as there is to the objective measurement of that world. Seeing and visualization, it is claimed, were as important to scientific understanding as rational thought and objectivity (Bortoft, 1996), a point also made by Østergaard (2015).

2.5.7 KNOWLEDGE AS EMBODIED

There is a growing body of literature around the idea of how our bodies play an essential part in how we make sense of the world and how we communicate (Claxton, 2015). Much of this is grounded in neurocognitive science. There is also considerable emphasis on language, usually derived from the work of Lakoff and Johnson (1999) which demonstrates the importance of metaphors arising through the links we make with the body and other bodily relations. Thus Gallagher & Lindgren (2015) show that enactive metaphors and whole-body involvement in virtual and mixed reality environments support and improve learning in science, an area also explored by Ahmet et al (2011). Such ideas may have resonances with current and earlier notions of experiential learning and learning by doing (Thiry, Laursen, & Hunter, 2011), linked to Dewey’s Experience and Education. Though care needs to be taken as both pragmatic philosophy and science has been significantly elaborated in the last century (Johnson, 2006).

The Rhode Island School of Art and Design’s natural lab provides opportunity for students to not only observe, and acquire information about the specimens, but provides the context in which to know the specimens by acting (by holding, moving, rearranging, drawing, making, etc.). The idea of knowing as
action, experienced through the body (as opposed to cognitive transmission) is advanced by authors across the cognitive and social sciences. Reflecting their experience of researching artists, Thomson et al suggest:

...knowing, doing and being ... is not separable’ and cannot ‘be planned for and learned/taught separately. Both epistemological and ontological learnings progress together, at the same time, and through one pedagogical practice. (Thomson et al., 2012, p. 11)

The notion of learning as being, as in the making: a process, through which ideas are ‘formed not finished’ (Thomson et al., 2012, p. 17), echoes Hughes and Lury’s (2013) view of knowledge as ‘events’ which recognise and bring to the fore the ‘dynamic interrelationship between living things and multiple milieus’ (Grosz in Hughes and Lury, 2013, p. 791). Van Boeckel argues, there is a need to ‘impart sensation of things as they are perceived and not as they are known’ (Van Boeckel, 2015, p. 116). This focus on meaning and sensation in the moment is supported by Hughes and Lury who argue for an emphasis is on how things change, not how they are.

The idea of knowing as a process centred on action links to growing literature on embodiment which argues for a view of the body as a site and engine for knowledge formation (Claxton, Lucas and Webster, 2010; Fuchs and Koch, 2014; Kontra et al., 2015; Stolz, 2015; Wilson, 2006; Horn and Denise, 2005).

Both Ingold (2010) and Denmead (2015) suggest that the arts provide perspectives on how ever-extending, complex ‘meshwork’ of interrelationships can be harnessed. Ingold argues that in creative pursuits, the work of art is not an object but a thing, which is a dynamic element, in formation within the relationship. The notion is common to art-makers who ‘often begin something without knowing how it will turn out. In practice, this translates as thinking through doing’ (Fisher and Fortnum, 2013). The role of the artist therefore is not to predict, to tie down, to plan scrupulously the exact outcome of the artwork, but as Ingold argues ‘to join in with and follow’ (Ingold, 2010, p. 125). He goes on to argue that ‘following is not the same as reproducing’ but is to ‘follow the ways of the world as they unfold, rather than to connect up, in reverse, a series of points already traversed’ (Ingold, 2010, p. 134). Denmead (2015) suggests that artists have particular methods for being prepared to follow during action including ‘distraction, relinquishing control, embracing chance, collaboration, following a hunch [and] privileging the senses over the intellect’ (Fisher and Fortnum, 2013, cited in Denmead, 2015, p.27).

2.5.8 KNOWING AS PERCEPTION

Arguments that either consider the nature of knowledge as located ‘out there’, or inherently part of the embodied experience of the subject, both bring into consideration the nature of perception. ‘To see’ or ‘to perceive’ can be interpreted, depending on context, in many different ways. In addition to the physical act of apprehending something in one’s field of vision, one might apprehend non-material characteristics of an object or person, for example, seeing its value, or another’s perspective, as in ‘seeing their point of view’. The process of sense-making (Weick, 1995) is an active process of coming to see order, that is creating order, in one’s sensuous world. In this creative process the seer utilises social resources to foreground (that is to see) certain features and not see others, to give value to particular perspectives (and not others).
Overstrom discusses this complexity stating that a fundamental lesson in the Rhode Island School of Art and Design is to ‘[l]earn to see by thinking more complexly about visibility’ (Overstrom, 2013, p. 93). The act involves seeing through or beyond the physically present. Thus, vision is more than a physical or sensory function; vision and thought affect our seeing and understanding. To see clearly, we must not only look more closely at visual objects and images, and their context, but also learn to imagine and interpret what is not visible.

Slightly differently a number of authors have suggested that the physical act of drawing an accurate copy of what is seen provides a valuable way into more complex seeing (Hodson, 2014; Van Boeckel, 2015). Van Boeckel argues that drawing can be a process of ‘cleansing’ in our seeing, as we take notice, look at exactly what is there in front of us and ‘allow one’s prejudices of how things ‘should’ look to fall away’ (Van Boeckel, 2015, p. 114). Hodson (2014) similarly talks of: ‘re-seeing’, which he defines as a re-focusing of attention on nuances and details in the environment. In particular, he argues re-seeing involves being wary and paying closer attention when we think we see everything.

Masschelein offers an alternative account to both Overstrom and Van Boeckel/Hodson. To see (or in his term gaze) is not about arriving at a liberated or critical view, but about liberating or displacing our view, ‘it is not about becoming conscious but about becoming attentive, paying attention’ (Masschelein, 2010, p.2). He argues that it is by making our gaze attentive that we bring together the subject (the seer) and object (the seen) and therefore it is not about arriving, but about displacing one’s gaze so that ‘we are (t)here and the (t)here can present itself to us in its evidence and command us (Masschelein, 2010, p. 45).

2.6 SECTION CONCLUSION

This section has reported on the initial exploration of STEM and STEAM and has identified a range of issues which emerge from contemporary literature. Albeit with limitations, this initial scoping of the literature allowed for the identification of themes and points of intersection amongst different sets of concerns, even though we recognise that authors reach these conclusions from different directions and for difference purposes.

As noted earlier, further to this initial phase of literature review, we moved on to consider literature which specifically linked one of the ‘STEM’ disciplines with the arts, or one of the arts. This constituted phase 2 of the literature review.

PHASE 2

The purpose of phase 2 was to draw together reviews in relation to the four STEM areas and the arts/art, and to review creative/arts based pedagogies. They are presented as five distinct reviews. Following the initial scoping of the issues, themes and debates prevalent in and for STEAM education, the core team conducted a number of more focussed keyword searches in relation to the four STEM discipline titles and the arts.

ERIC and World of Science searches were made for:

(a) STEAM education; Science education + arts; Mathematics education + arts (also includes Maths education + arts); Technology education + arts; Engineering education + arts.
(b) The ‘arts’ keyword was then replaced with the specific arts practices: music, drama, dance.
(c) Finally, ‘arts’ was replaced with ‘creativity’.

The searches conducted in (i) resulted in a large number of results, especially from the USA where reports appeared to be versioned for different States. The decision was made to limit these searches to academic publications, filtering out references to grey and policy references. A positive effect of limiting the searches to academic sources was that it indicates how far the search term combinations have penetrated to a level of theorising and scrutiny.

The searches conducted in (ii) led to different challenges. Some results only fleetingly referencing one or other of the search terms, or only using them illustratively of wider curriculum discussions. These searches were limited to searching for the STEM discipline in the abstract, but the arts practice in the whole article.

A further keyword search was made of the databases drawing together work on ‘creative pedagogies’, ‘creative pedagogy’, Arts based pedagogies’ and ‘Arts based pedagogy’. Again, there was the challenge of shifting out results in which these terms were fleeting or marginal to the argument in the paper. Given the relatively small number this was done through a consideration of the abstract.

Different members of the core team undertook the task of developing a coherent narrative, in relation to each STEM subject. They considered the literature to identify: ‘the state of play’, key points emerging from the literature, and, against the background of the phase 1 review, important gaps.

Searches on the different STEM disciplines generate significantly different number of results (from 309 for Science to 41 for engineering). This was perhaps to be expected, but the relatively low number of results for mathematics in comparison to Science (74 as opposed to 309) may indicate that further work is needed to identify whether this is an artefact of the search process or a reflection of the differential concerns of mathematics and science educators.

### 2.7 SCIENCE EDUCATION (PLUS ARTS, MUSIC, DRAMA, DANCE; STEAM EDUCATION)

#### A. Key themes/questions

(i) Need for more long-term, longitudinal studies exploring the effect of arts-infused and arts-integrated approaches into the science classroom.

(ii) Support teachers’ understanding and use of creativity and arts-based methods in science.

(iii) Need for clarification and distinction between creativity and arts-based methods.

(iv) How can we develop a more embodied science education, integrating, and involving arts-based approaches?

#### B. Commentary

Much of the literature and policy documentation around STEM education emphasises the economic and competitive rationale for increasing uptake of STEM related careers (European Commission, 2004; National Academy of Sciences Committee on Science Engineering and Public Policy, 2005; Treasury, 2006). However, the liberal arts and humanities are also seen as necessary foundation for
the STEM disciplines (Daugherty, 2013), through cross-cutting domains such as rhetoric, orthography, ontology, and teleology (ROOT) disciplines (Badua, 2015).

A similar argument appears regularly in the science education literature. Examples of projects, not always exclusively with science (e.g. Mason & Steedly, 2006; Gurnon et al., 2013), include the use of puppets to promote engagement and talk in science (Simon, et al., 2008); the role of music in enhancing or engaging with science in the classroom (Gershon & Ben-Horin, 2014; Sargeant & Simpson, 2002; Goldman, Yalowitz, & Wilcox, 2016); the significance of aesthetic experiences in primary science education (Milne, 2010); the enrichment of medical and science education through poetry and other media (Brown, 2015). The focus is primarily on the enhancement of science education and generic skills through the integration of arts. We note the dominance of studies based in primary school, although a few examples have also been found in secondary, particularly drama-based activities (for a review, see Dorion, 2009).

While STEM education may be a policy priority, according to Ghanbari (2015, p. 1): “the arts have the ability to open up new ways of seeing, thinking, and learning”. Such views are also expressed by others (e.g. Root-Bernstein, 2015; Sener et al., 2015) arguing for arts-integration or “combining diverse elements into harmonious wholes with a synergistic result” (Cornett, 2011, pp. 15-16 cited by Steele & Ashworth, 2013).

Recognition is given to problem-solving inquiry emphasised by STEM disciplines as well as exploration of uncertainty, ambiguity, and fuzzyness enabled by art education and curricula (Daugherty, 2013, p. 12). Wynn & Harris (2012) and Boy (2013) extend this argument further by drawing on complexity theory and suggests that creativity should be promoted together with rationalization, thus moving to STEAM (with an “A” for Arts). Evagorou et al. (2015) consider the use of visual representations such as photographs, diagrams, models to renew attention for how visualization contributes to knowledge formation in science education. In a similar way Rudolph (2015) argues for greater attention to the methods of science, as opposed to the body of consolidated knowledge. This brings the question of how scientific creativity may be stimulated in science education (Schmidt, 2010; 2011).

Creativity is sometimes associated with problem solving (Cardellini, 2006; Aldous, 2007); in other cases, it is linked to teachers’ attributes (Ayob, Hussain, & Majid, 2013) or creative practitioners working in collaboration with classroom teachers (Galton, 2008, 2010). While Demir (2015, p. 693) defined scientific creativity as a “thinking ability that brings together interdisciplinary areas of science, technology, and art (aesthetic)”, students tend to have rather superficial ideas of scientific creativity. Much literature on creativity tends to focus on unique individuals, or “special talent” creativity, as opposed to creativity as “self-actualizing” in the science classroom (Hadzigeorgiou et al., 2012). Fewer studies investigated the effectiveness of creative approaches. Sener et al. (2015) found that creative approaches increase students’ attitudes towards the subject however, it was difficult to separate out the effects of outdoor and laboratory activities, as well as more arts based activities. Similarly, many authors (Kind & Kind, 2008; Girod, Rau, & Schepige, 2003; Liu & Lin, 2014) identified a link between creativity and divergent thinking and problems solving in science, yet without mentioning art-related activities. There appear to be several areas for attention in teacher education related to inquiry and creativity in early years’ science and mathematics education (Cremin et al., 2015; Stylianidou et al., 2013; Shanahan, and Nieswandt, 2009). Within all the studies there is often reference to attitudes or
perspectives towards arts and science, as in STEAM, but the distinction between what creativity is with respect to science and the arts remains problematic (Daskolia et al., 2008; Demir, 2015; Šorgo, 2012).

A small number of papers, primarily from a critical pedagogy perspective, examined the role of arts and aesthetic experiences. The use of the arts pushes the individual to see things in a different way, as a counter to “the challenges faced in urban science education [which are] deeply rooted in the ongoing struggle for racial, class and gender equity” (Calabrese Barton, 2001, p. 899). Prominent in these accounts, although limited in number, is emerging research drawing on embodied learning. Chappell (2008) states that “several ground-breaking collaborations have seen scientific concepts as complex as epigenetics and neural activity in the brain explored through dance” (p. 160) and Alsop (2011) reiterates how “Students’ and teachers’ bodily acts now emerge as important facets of science education” (p. 612).

From this orientation, literature also focussed on the arts in connection with the ability to find creative solutions to “wicked problems” (Aikenhead, Calabrese, & Chinn, 2006; Alsop & Bencze, 2009; Colucci-Gray et al., 2006; Sophia & Hyoungbum, 2015; Krug and Shaw, 2016). The arts are used as a methodology to assess children’s love of nature (Aktepe, 2015); perceptions of different environments (Sorin & Gordon; 2012); children’s and adults’ constructions of sustainability issues (Lawson et al, 2005; Barraza & Robotom, 2008); young children’s conceptions of rainfall (Villarroel & Ros, 2013; Hsieh & Tsai, 2017). Daskolia et al. (2008) examined Greek teachers’ views of creativity with respect to environment education and concluded that creativity, with drama and plays, can be paired with social and ecological responsibility. In “Pedagogy is defined broadly”, Thomson, et al (2012) refers to the shaping of the learning environment as a whole, in classroom settings, and more widely in the school and community. The impact on teachers of the different pedagogies employed by artists is explored to the extent to which they promote inclusion (Hall, Thomson, & Russell, 2007).

2.8 TECHNOLOGY (PLUS ARTS, MUSIC, DRAMA, DANCE, CREATIVITY)

Note: there is a potential conflation between the use of technology in learning (for example, technology enhanced learning, TEL) and learning about technology. The latter may be seen as the content of Technology lessons (for example, Design Technology, ICT, some subject areas in science). Here we report on only those papers clearly concerned with arts practices.

A. Key themes/questions

(i) Creativity and Design are common features across the arts, technology, and engineering.

(ii) Materiality, engaging with materials and the idea of ‘making’ things/art-making, are cross-cutting features of engineering, technology, and the arts.

(iii) Technology in STEM is seen as being largely a vehicle to facilitate learning, by providing a practical context for learning abstract concepts more effectively; similarly, the arts, are seen as means for engaging youth.

(iv) Critiques from the field of technology education highlight the need to bring more contemporary topics to the technology education agenda, for example, agriculture, medical technologies.

(v) There is a need for greater awareness of issues of gender and ethnicity, and how technology is interwoven with cultural constructions of gender and the body.
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(vi) Several recent innovative approaches integrate technology and the arts, with pioneering examples from music. Features of these approaches include: knowledge-creation; trespassing of disciplinary boundaries and reformulation of conventional teacher-student relationships.

(vii) Pedagogically, the involvement of the arts and sciences is seen as promoting the development of metacognition in students, particularly through the contribution offered by the arts in enhancing conceptual thinking.

(viii) STEAM approaches are seen as vehicles for preparing future scientists to be more competitive, while other authors see them as means for exploring issues of sustainability and climate change, though enhancing metacognition.

(ix) In emerging economies (Africa, Malaysia, India) the use of technology in education is largely deployed for the purpose of dissemination of information to a large audience at the expense of learning about technology.

B. Commentary
Technology has an ambivalent position, both in relationship to other STEM disciplines and to schooling (Pinelli and Haynie, 2010). As a discipline, it draws directly on science and engineering and treats mathematics as ‘a way of life and tool of the trade’ (Pinelli and Haynie, 2010, p. 53). Whilst technology is not a discrete curriculum subject in UK schools, it is at present part of design. In this regard, Hansen (2009) and Fantz & Katsioloudis (2011) report that the integration of technology and engineering can provide the practical context required to learn scientific concepts more effectively. Further, there is evidence that the integrative, applied nature of engineering/technology can enhance student learning, boost test scores, and help schools meet standards-driven education requirements (Baker, 2005; Silk, Schunn, & Strand Cary, 2009). Its collaborative, social aspects have also been shown to appeal to students who the field has traditionally failed to engage, including females and underrepresented minorities (Geddis et al, 1993; Wiest, 2004, Rask, 2010; Reichardt, 2013).

O’Riley (1996), anticipating Reed and LaPorte (2015), points to the need for redefining the aims and practices of technology education from a feminist perspective, foregrounding the ethical dimension. According to Faulkner & Arnold (1985), Leto (1988), and Wajcman (1991), technology is described as a “social tool” to both construct and maintain stereotypical gender roles. Going further, some feminist researchers point to women’s bodies becoming increasingly colonized by new reproductive technologies (Corea, 1985; Duelli Klein, 1987; Haraway, 1991).

Technology has a distinctive role to play in the arts and in design technology education (Bastos, 2010, Mayo, 2007). However, there are challenges, including:

- Art teacher technology competencies (Black, 2009; Phelps & Maddison, 2008)
- Obstacles of art and technology integration (Delacruz, 2004; Wood, 2004), and the challenges and potential of art and technology infusion (Delacruz, 2009a)

Some areas of the literature look at the integration of technology into education as a means to reformulate traditional learning habits. For example, the importance of creativity and drawing on the
language of ‘making’ and ‘materials,’ is apparent. This includes: understanding how to make things (Reichardt, 2013), creative brainstorming (Starkweather, 2011) and getting a “feel” for how strong materials are in building prototypes (Sirinterlikci et al, 2005). For Gouzouasis (2006, p. 5) ‘[t]he role of art is to liberate humans from the mechanical status that they impose on themselves by merely using and adapting to technologies’.

Dale (2008) defines more clearly the purpose of the integration of technology with arts, pointing to the role of the arts in promoting higher order conceptual thinking. Similarly, Halverson and Gibbons (2010) signal the importance of students being able to discern and articulate the relationship between the idea in the design process and the representational tool to be used.

Examples of projects including the arts, and used to give learners a real and active agenda, include Chung’s (2007) description of the application of digital storytelling to art education as an interdisciplinary, inquiry-based, hands-on project that integrates the arts, education, local communities, technology, and storytelling (see also Delacruz, 2009b). Further, technology can promote access to the arts and a shift in pedagogical practice from learning about technology to creating with technology, challenging classic hierarchy of amateur and professional (Cayari, 2011; Greher, 2011). Also, ideas of gender preferences may be challenged towards a more inclusive and diversified view of how different pupils make use of computing technologies (Mims-word, 2012), and how they can work with sound overcoming the restriction of standard, Westernised music notation (Crawford, 2014).

Hope (2009) argues that technology education should not be seen simply from an instrumentalist viewpoint as a preparation for the world of work, but as a preparation for full functionality in human society (see also Blair, 2014). Similar ideas are expressed in the premises of indigenous education. The foundations of American Indian life for discovering one’s true face (character, potential, identity), one’s heart (soul, creative self, true passion), and one’s foundation (true work, vocation), all of which lead to the expression of a complete life (Cajete, 1994).

2.9 ENGINEERING (PLUS ARTS, MUSIC, DRAMA, DANCE, CREATIVITY)

A. Key themes/questions

(i) The majority of sources related to small-scale studies; no meta-studies were evident.

(ii) Few of the sources were UK based, with the key ones being American or Canadian. The richest sources for the STEAM agenda appeared in the Art Education Journal, with one on the American Journal of Engineering Education.

(iii) Design particularly, and in some studies art making, is recognised as a valuable site, practice and process for learning engineering.

(iv) Engineering is recognised as problem-solving, which draws in different disciplines and skills. This interdisciplinary characteristic is appealing to, and echoes qualities of, design and technology education. It is also valued, by a number of educators, for naturally positioning children as enquirers and problem-solvers. Thus, supporting the recognition and development of creative dispositions.

(v) Engineering education (typically sited in higher education), like design and technology in school education, is conceived as a material, ‘doing’, project-based experience with situated learning.
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(vi) Several papers explore how engineering, currently not explicitly part of the school curriculum, might be introduced and to what advantage. Here arguments relate to practice-based learning, skill development and interdisciplinarity.

(vii) Engineering is often described as a ‘creative’, design-like practice. However specific conceptualisations of ‘creative’ or ‘creativity’ are rarely evident. Some accounts identify that creative skills are useful to be develop for, or through, engineering education.

(viii) The pedagogy of engineering education does not appear to have been a focus of research or significant theorisation.

(ix) Innovative approaches advance inter or even transdisciplinarity, particularly with art, but also with sustainability and social agendas.

B. Commentary
This engineering education literature, characterised by small-scale studies, appears to suggest a strong relationship with creativity, but also, and most strongly, with design (in terms of the arts). It does not often appear to attend to the ontologies and epistemologies of engineering. Although research into design pedagogies may reflect the kinds of theories active in science education and design pedagogy, such as new materialism and situated learning (Tovey 2015), such theories are often implicit rather than articulated and debated. Our observations arguably may relate to the status that engineering and engineering-like practices, including design and technology, have in the school curriculum and the history of engineering as a practice-based craft. It may be useful to consider design pedagogy for insights on design as a site for creative engineering, with or without direct reference to the arts.

Engineering is seen as a rich site for collaboration using problem-based learning (Bequette and Bequette, 2012; Asiabanpour et al., 2010, Costantino et al. 2010). Bequette and Bequette (2012) also argue for attention to the varied realisations of STEM in school and for teachers to ‘investigate the STEM approach in their school’, and ‘discuss and examine aesthetic decisions or scientific evidence’ (p. 46). Indeed, the idea of debate and reflection is echoed in Donner and Wang’s small scale study (2013) which suggests that design thinking at university is often not transparent or debated.

A rich STEAM like study was offered by Guyotte et al. (2014) of a Transdisciplinary Design studio project (with art and engineering undergraduates). They argue that the tradition of conceiving of art as a social practice (since Dewey) is also applicable to engineering. This transdisciplinary approach employed creative thinking, art, and engineering tools and processes to address open, socially and ecologically informed, ‘big’ questions. This approach attuned and sensitised students to the ‘domain precise’ and relational dimensions of engineering. It supported an enriching re-visioning of a problem, and of learning, through multiple layered and simultaneous frames of art, engineering and ecology, which is social in character.

2.10 ARTS BASED PEDAGOGIES (PLUS ARTS, MUSIC, DRAMA, DANCE, CREATIVITY)
A. Key themes/questions
(i) There is strong evidence of systematic research in the field of ‘arts-based pedagogies’. Much of the literature focuses on pupil learning, achievement, wellbeing and the associated value of teacher professional learning with artists (Sharp and Dust, 1997; Pringle, 2002; 2008; Trowsdale, 2002; Thomson et al., 2012; Galton, 2010; Holdhus and Espeland, 2013).
Much of the research in the area of artist-led arts pedagogies has focused on identification of the characteristics of learning experiences that are thought to be effective in supporting student learning (Thomson et al., 2012; Denmead and Hickman, 2014).

Findings foreground qualities of enjoyment, inclusion, engagement, transformative thinking, deep knowledge (knowing the central, crucial ideas of a topic and establishing complex connections) with deep understanding (of the topic in a systematic way), substantive conversation (interactions on the topic among students and with teachers) and agency (Robinson, 2013).

Plausible mechanisms for the development of these educationally positive aspects are: (i) increased motivation, (ii) making the abstract concrete, and (iii) the enhancement of group work. However, the lack of theorisation means that any extrapolation to general claims needs to be treated with care.

Arts based pedagogies require, and are characterised by, arts based learning, artistic processes, artistic discourses, artistic expression, artistic tools and materials, often with the development of a performance or presentation (a performative outcome). The learning journey is often driven by a creative impulse to the finished product making the processual and procedural aspects of immense importance to the students (Marshall, 2015).

Art is used as a medium for cultural and social transformation, for facilitating dialogue, for participatory, inclusive journeying, exploration, and discovery, in transdisciplinary spaces (Guyotte et al., 2015).

B. Commentary

The term ‘arts-based pedagogy’ is used interchangeably with, ‘arts-based methods of teaching’, ‘arts-based pedagogical approach’, ‘arts-based instruction’, ‘arts-based learning’, ‘integrating art pedagogy’ and ‘teaching with the arts’. The arts, as ways of apprehending and comprehending human reality and society, are important areas of knowledge in their own right. In spite of their often marginalised position in educational curricula world-wide (Deasy, 2002; Bamford, 2006) the literature argues that they are powerful instruments of pedagogy that can augment, illuminate, infuse, integrate and unify the whole curriculum. Arts-based pedagogies are increasingly emphasised as significant for teaching generally – in terms of improving learner outcomes (literacy, numeracy, technology, and the natural and social sciences), developing learner capabilities, motivation, and self-view, as well as vital co-curricular elements such as the ethos and social relationships (Harland et al 2000; Eisner 2004; Fleming et al., 2016). The approach has traction for STEM-to-STEAM in describing the application of ‘arts’ to enhance educational experiences and outcomes. Pool et al. (2011) highlight the benefits for enhancing student enjoyment, engagement and understanding, as well as the evidence that teachers value arts-based approaches when they are embraced (see also Catterall, 2009; Furman et al., 2016).

Arts-based pedagogies situate art at the centre of the learning journey: arts materials and artistic processes enable abstract, personal, and literal dialogues about ideas and the role of arts in life. Arts-based pedagogies facilitate the exchange of knowledge from different perspectives, disciplines and contexts and provide an understanding of different artistic learning processes. Projects are often completed with site-specific performances or presentations – ‘spaces’ and modes in which students’ emotions, are integral to the learning (Myers, 2012). Artistic practices are essential aspects of art-based pedagogies.
There are seven meta-analyses which have consistently found academic benefits for arts participation. However, pooled effect sizes range widely and are not consistent. There are some indications of patterns of effect, such as a higher impact for younger children and for music studies, but these are not consistent. The quality of evaluation designs used by studies of arts participation has been criticised as insufficiently robust to draw causal inferences in recent reviews (Fleming et al., 2016).

Nonetheless, across meta-analyses and small-scale studies there is evidence that children learn effectively through experiencing and making in the Arts (musical, linguistic, visual and design, dance, and dramatic play). Learning happens through play and playfulness; when they explore, and construct their own meanings, and discover and make sense of the external and their social world. Children simultaneously use all their senses (physical, emotional, and cognitive); by trying things out in ‘safe’ settings; by trial and error and in creative leaps. Learning happens collaboratively, through copying, observing, social interaction and building on what they already know.

Studies of artists’ pedagogies have generated similar and valuable insights into the conditions or ‘platforms’ that can be modelled for, and facilitate in, education. Thomson et al (2012)’s study drew upon eight case studies. They identified the value of sociality and relationships, including valuing, and modelling interactive, collaborative and cooperative ways of working in which individuality features, and where choice and agency are enabled. They noted the creation of a space, physical and symbolic, in which the institutionalising influence of the school can be suspended, and where the absurd, carnivalesque and large scale ambitions are possible. Cunningham, (2015) and Denmead and Hickman’s (2014) year-long study of a similar scale drew on the practice of eight community artists. Their study echoed similar points about how artists create conditions for open-ended enquiry across: space, time, material, body, and language.

### 2.11 MATHEMATICS EDUCATION (PLUS ARTS, MUSIC, DRAMA, DANCE, CREATIVITY)

#### A. Key themes/questions

(i) There is little evidence of systematic research in the field. The majority of the literature is concerned with small scale evaluations or theorisations of evaluations. There is little evidence of cumulative force.

(ii) Whilst the majority of the literature is concerned with the mathematics classroom, there is considerable concern with the use of mathematics in other school subjects (mostly science and technology).

(iii) Much of the pedagogical and curricula literature focusses on atypical mathematics education practices which are often articulated as creative/innovative/novel/etc., or the reverse.

(iv) There is little evidence of agreed definitions of key terms (even creativity), and the literature is difficult to synthesise.

(v) Well managed, creative approaches to mathematics education appears to improve pupil outcomes.

(vi) The mechanisms for this improvement are plausibly: (i) increased motivation, (ii) making the abstract concrete, and (iii) the enhancement of group work. However, the lack of theorisation means that any extrapolation to general claims needs to be treated with care.

(vii) Mathematics education benefits from external educators, often drawing on more creative approaches, and utilising specialist resources (equipment or personal skills).
(viii) Mathematics education for those with additional learning needs requires adaptation of general resources and creativity from the teacher.
(ix) The use of technology is generally positive when linked to specific learning activities and goals.

B. Commentary
Any review of the field needs to take account of its lack of coherency as a body of ‘knowledge’ (see Lonergan, 2007 and Sriariman, 2004, as exceptions who both seek to develop a more systematic approach to considering creativity in maths education). There are a limited number of key texts or authors whose work is consistently referenced (e.g. Boaler, 2003), and this may reflect the texts deemed important to ‘teachers-in-training’ rather than the distinctive contribution to the research agenda. The literature itself can be helpfully categorised in the following way:

• As concerning specific examples of creative or innovative practices in and beyond the classroom;
• As concerning institutional (see Lindahl and Cain, 2012) and policy arrangements for mathematics education reflecting changes to the organization and coherence of a pupil’s experience of mathematics education over time (see Caliskan Depeoglu and Alat, 2012), or the locations of mathematics in the school curriculum (e.g. the rise of ‘numeracy’ as distinct from mathematics, see Welsh Government, 2013);
• Reflections on, and analysis of, the international comparison tools for mathematics, most notably PISA (see Kirwan, 2015);
• The utilisation of mathematics of a site for the discussion of broader educational issues, e.g. additional learning needs (see Barrett and Fish, 2011; Storeygard and Tierney, 2005), the learning objectives of schools, teacher professional development (see Frickey, 2007; Morgan, Parr and Fuhman, 2011), the effect of testing (see Nichols, Glass and Berliner, 2012).

In this review, the first of these was, unsurprisingly, the major source of literature, accompanied by a selection of the latter category especially those relating to gender, class, etc. as a distinctively important indicator of success, or motivation in mathematics education (see Deniz, Ture, Uysal and Akar, 2014; Aslan, Canli and Sabo, 2012; Braathe and Solomon, 2015). In addition to this literature there was a range of papers on the support need for mathematics teachers-in-training, including subject knowledge (see Betts, 2005; Varghese, 2009; Solomon et al., 2015) and pedagogical skills (see Rodrigues, 2012; Ozgen and Alkan, 2014).

As noted previously, the difficulty in offering a coherent summary of the range of literature concerned with creative or innovative practice stems from its lack of cumulative force: there is insufficient building on, and testing of, ideas; it is small scale and evaluative in nature; and lacks theorisation. It is possible to make some very general claims, for example in relation to methodology that there is a tendency to utilise cognitive psychology to explore teachers’ and pupils’ approaches to mathematics (see Pateman et al, 2003; Hoines et al, 2004), and more sociologically inspired analysis for exploring classroom practices. Nevertheless, these are relatively unhelpful in presenting a coherent account of the relationship between mathematics and arts practices. In terms of more general themes in the review, it may be worth drawing attention to some recurring themes and motifs, without indicating their importance for mathematics education:
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- A concern with problem solving (Bottge et al., 2004; Novita, Zulkardi and Hartono, 2012)
- A concern with the potential value of ICT (Akiva, Povis and Martinez, 2015; Morgan, Parr & Fuhrman, 2011; Binterova & Kominkova, 2013), especially the value of tablets (O’Malley et al, 2014)
- The potential of video (Ahmad et al., 2013; Gainsburg, 2009; Lazarus & Roulet, 2013) and online learning to extend teaching opportunities (Lee, 2014)
- After school and additional support for mathematics (Kliman, Jaumot-Pascual & Marton, 2013; McVarish & Birkmeier, 2004; Dave et al., 2010; Lindberg et al, 2008)
- The role of mathematics in other science and technology disciplines (Tekerek, Yeniterezi & Erkan, 2011; Colvin et al., 2014; Fanvesi, K. et al., 2016)
- Some identification of the value of pattern recognition as a form of art, especially in relation to certain religious traditions (Gigantic and Cittadino, 1990)

Further, the literature makes specific links to arts practices through links with embodied learning:

- Music (Neyland, 2004; Bahna-James, 1991)
- Dance (Helsa and Hartono, 2011; Rosenfeld, 2013)
- Arts (Bequette & Bequette, 2012; Tavin, 2008; Wynn & Harris, 2012; Hekimoglu, 2010)
- Multi-disciplinary work (Wicklein & Schnell, 1995; McMullin & Reeve, 2014; Deasy, 2002; de Freitas & Ferrara, 2015; de Freitas & Sinclair, 2014)

Finally, it is worth noting a limited critical engagement in the values related to mathematics education. Exceptions here include Herner and Lee’s (2005) discussion of the question of access to mathematics education in special education settings, and Davidson’s (2007), Boylan & Povey (2012) and Boylan (2016) discussions of the value of mathematics in addressing issues of social justice.

### 2.12 Creative Pedagogies

**A. Key themes/questions**

i. Creative pedagogies are characteristically learner-centred. They promote engagement and a questioning stance. They also firmly foreground values of creating ‘shared’ space and time, and the freedom to make connections. They make a feature of, and promote multimodalities and improvisational strategies. Among their aims are process-based ownership and ongoing reflection, modelling, risk-taking and problem -posing -seeking and –finding (Lucas, 2001).

ii. One of the ways in which creative pedagogies is manifested and characterised is through ‘possibility thinking’ (Craft, 2001, 2002). This involves asking ‘what if’ and thinking ‘as if’ (Craft, 2001, p. 50). This model has been developed subsequently by numerous scholars through both theoretical and empirical study (e.g. Burnard et al., 2006; Chappell et al., 2008; Craft, Cremin et al., 2012).

iii. Creative pedagogies are also evidenced in studies which explore collaborative creativity and engagement. These dimensions are well established in the literature as features of a creative pedagogical stance (Cremin and Arthur, 2014).

iv. There is a vast and disparate literature on creative pedagogies. These include situating the discussion in terms of: character (Harris, 2013, 2014), school practices (Craft, 2000; 2010),

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*Interesting, and we think uniquely, Hekimoglu addresses the issue of ‘martial arts’.*
higher education (Jackson et al., 2006, Burnard & Haddon, 2014), the creative industries (Harris, 2014), creative cities (Winkler & Denmead, 2016), and creative practitioner partnerships (Denmead, 2015, Thomson et al., 2012, Galton, 2008).

v. Much of the recent literature characterises creative pedagogies as those that are flexible, adaptive and generative (McWilliam, 2008). There is also a great deal of writing on creative teaching or teaching for creativity (Pope, 2005; Lucas, 2001). However, the dominant narrative sees ‘creativity’ politicised and re-appropriated for any number of political and economic arguments and for understanding social change (Thomson et al., 2012; Lin, 2012).

vi. Much of the pedagogical and curricula literature shifted gear in recent times, and distances itself from a focus on artist creative partnerships in education settings. Whilst these practices are often articulated as creative, innovative, and novel (Denmead, 2015); teachers’ pedagogic approaches focus on team teaching, cross- and inter-curricula, dispersed, informal-formal, and personalised learning approaches and diverse creativities (Burnard & Haddon, 2014; Burnard, 2015).

vii. There is little evidence of agreed definitions of key terms (even ‘creativity’), and the literature is difficult to synthesise. Definitions have been developed in the field of creative learning (Banaji, et al, 2010; Jones and Wise, 2012).

viii. Creative pedagogies are often described as involving three types of engagement (and framing): (a) co-participation, (b) collective engagement and (c) collaboration. Other dimensions commonly theorised include: imagining and making connections, and generating multiple possible solutions (Sefton Green & Thomson, 2011; Craft et al., 2012; Spendlove & Wyse, 2007; Thomson et al., 2012).

ix. Creative pedagogies now make more frequent use of technology and digital ‘maker’ practices which have a positive effect when linked to specific learning activities and goals (Ruthman & Dillon 2012).

x. Signature pedagogies appear significantly in the creative pedagogies literature. Defined by Lee Shulman as ‘the types of teaching that organise the fundamental ways in which future practitioners are educated for their new professions (2005, p. 52). These “signature pedagogies” reflect the deep structures of the discipline or profession. Signature pedagogies are important “precisely because they are pervasive. They implicitly define what counts as knowledge in the field and how things become known” (Shulman, 2005, p. 54).

B. Commentary

There are a number of key texts or authors whose work is consistently referenced and this marks a distinctive contribution to research rather than a policy agenda. In particular, a growing consensus is developing on the significance of ‘signature pedagogies’.

It has been long recognized that academic disciplines also have distinctive habits of mind (or habitus) that characterize disciplinary pedagogies (i.e., signature pedagogies are not unique to certain professions) (Chick et al., 2012; Gurung et al. 2009). These “signature pedagogies”, a term first coined by Shulman, (2005), are types of teaching that reflect the deep structures of the separate disciplines, and attempt to answer questions such as:

- What does our pedagogy reveal, intentionally or otherwise, about the habits of head, hand, and heart as we purport to foster through our disciplines?
• Is there, or should there be, a consistent connection between a way a discipline creates or discovers new knowledge and the way it apprentices new learners?

‘Signature pedagogies’ build on widely accepted assumptions about what leads to significant learning, drawing upon a number of earlier works (Huber & Morreale, 2002; Pace & Middendorf, 2004) as well as offering rich questions for exploration within the field. Signature pedagogies are important “precisely because they are pervasive. They implicitly define what counts as knowledge in the field and how things become known” (Shulman, 2005, p. 54).

Thomson et al (2012) focus on the work of creative practitioners, mainly artists, in a small number of English primary and secondary schools. They seek to identify the distinctive (‘signature’) pedagogies that the artists helped to shape. Pedagogy is defined broadly as the shaping of the learning environment as a whole, in classroom settings, and more widely in the school and community. The report constructs a framework of analysis through which the different elements and emphases of arts-related signature pedagogies can be explored in detail. On this basis, it presents eight case studies of creative practitioner pedagogy, highlighting the knowledge resources from which they draw, as well as their affective dimensions. Throughout, they are concerned to explore the differences between arts-related signature pedagogies, and the ‘default pedagogy’ established in schools by a ‘standards agenda’ that defines excellence in terms of progress against a limited set of measurable indicators. The study concludes that there is much that schools can learn, and are learning, from the pedagogies of creative practitioners.

2.13 SECTION CONCLUSION

This section drew together reviews related to the four STEM areas and the arts, and the nature and purpose of creative pedagogies. As in phase 1, we have sought to identify key themes in the literature as a whole, rather than taking a genealogical approach to the way particular arguments have emerged over time. The aim was to record the ‘state of play’ in the STEM/STEAM literature, and to indicate limitations of present framing of arguments as well as opportunities for extension. It is against this backdrop that we report on a series of ‘Extended Dialogues’ held with key stakeholders.
3. EXTENDED DIALOGUES

As indicated in §2, the Extended Dialogues were designed to address the three, thematic areas of the review. Each dialogue invited people to come together to reflect on the opportunities of STEAM to extend learning beyond single disciplines, and to explore what might be emergent conceptions of knowing and learning. Each time we invited different contributors (See Appendix E). The purpose was to stimulate discussion from a range of theoretical and practical perspectives in relation to educational theory, teacher education and schools. Geographic and historic locations were dimensions in determining the participating community in each area. Each Extended Dialogue is described, and reflected on, by the host.

3.1 COMMISSION ROUNDTABLE: ABERDEEN

Programme
The purpose of the commission roundtable was to inform the tenets of the review and plan for presentations grounded in educational research at the Extended Dialogues. The commission provided expertise covering broadly the field of education. This contributed to setting the initial discussions within a spectrum of theoretical positions. It involved a set of 11 academics (including members of the core team). The roundtable took place over two days, Tuesday and Wednesday, 17th and 18th February. On the first day, the commission reviewed educational discourses which may be associated with STEM and STEAM and considered a range of different conceptions of knowledge. Inputs from discussions were recorded on an online platform, padlet, for further review. At the end of the first day, the core team met to collate inputs from the day and initiated the theme-rheme document (Appendix A), which was shared with the commission the following morning for feedback and refinement. On the second day, the commission addressed the purpose and design of the literature review, with consideration of the multi-vocality of STEAM.

Discussion on the first day took place in small groups; while on the second day we gathered in a round table for a whole group session followed by an arts-based activity, “modelling one’s hand in clay” (Appendix B) led by Jan Van Boeckel. The activity was designed to invite participants to explore the value of the knowledge promoted by arts-based approaches to learning and connections with the sciences. In the afternoon, commission members met with members of the core team to share initial thoughts about the design of the Extended Dialogues in Cambridge and in Warwick. Due to the timescale of the project, the dialogue in Aberdeen had already been planned via exchanges with commission members by e-mail. Planned inputs for the Aberdeen dialogue were shared with the commission with an understanding that more information would be made available via regular updates on the website (https://steamresearch.wordpress.com/).

Commentary
On the first day, the commission identified and discussed a broad spectrum of conceptions of knowledge, ranging from positivistic to constructionist, feminist and materialist perspectives.
There was debate about the relevance of different and dominant discourses. One group commented on these challenges: “as long as conceptions of knowledge and knowing are not challenged directly, no learning theory will successfully introduce a new approach to learning and teaching” (comments from day 1). Similarly, questions were raised about the nature of science, and ways of knowing of different scientific subjects, distinguishing further between the ‘arts as practices’ and ‘the value of the specific skills/virtues dominant in the arts’. It was also clearly recognised that alternative ways of knowing may challenge existing understandings of STEM education and the feasibility of STEAM in different educational contexts (i.e. from primary through to Higher Education), a problem made more acute by the lack of past examples.

Reflections from the second day included discussion of the tenets and approach to the review. The commission panel was clear that developing an ongoing, thematic, reflexive narrative was better suited than following an overly structured or predetermined action-plan. This approach was then revisited through a clay-modelling activity held in a science lab (see Appendix B), which enabled trans-disciplinary exploration and insights into contested and uncertain topics such as ‘what is STEAM’ and what is the role of the arts. While the activity unfolded through structure and guidance from Jan, the artist facilitator, participants followed their own, tactile sensations of modelling clay. Reflection focussed on personal beliefs as well as memories of past experiences of being in a situation requiring to follow a protocol, such as performing a science experiment at school. Some people re-interpreted the instructions; others felt they could not engage with the process/had to stop; while some other people meticulously followed the guidance. One female participant recalled feeling uneasy in the presence of the male teacher instructed to shut your eyes during the science lesson. She felt earlier sensations in her own body, sensations of ‘being coaxed into doing things she did not want to do’. Other comments focussed on sensorial awareness, and the silence that filled the room. There were also questions about the nature of the activity and whether it had anything to do with science; whether it was science. Some people identified connections with physics, anatomy, and biology, such as the experience of ‘heat’ generated through contact with clay.

In summary, reflections post-activity centred upon relationships between teachers and learners; focussed attention and emotional engagement. Critical was the intersection between different disciplines and ways of knowing mediated by the body. This space allowed for exploration and possibilities but it was also difficult and uncomfortable to inhabit.

3.2 CHANGING CONCEPTIONS OF KNOWLEDGE: ABERDEEN EXTENDED DIALOGUES

Programme
Hosted by Laura Colucci-Gray, the aim of the day was to explore changing conceptualisation of science and arts, the first theme explored by the review, and to discuss learning possibilities associated with the arts. The event took place on Thursday 18th February, in the Sir Duncan Rice Library, at the University of Aberdeen.

Teacher educators (7), school teachers (2), doctoral students (2), Aberdeen city council development officers (2), anthropologists (2) and artists (3) engaged in small table discussions and plenary activities. Post-its were used to track participants’ impressions after each presentation, focusing on “established ideas”; “new ideas”; “surprises”.


Firstly, Donald Gray invited participants to share in the recognition that current issues are no longer the realm of scientific inquiry alone. They are calling for the engagement and inclusion of different approaches to designing, conducting and validating research. Specifically, Donald pointed to the shift from science as description of reality to techno-science, an enterprise of transformation of the global environment, which raises critical questions of methods, social participation, and ethics.

Further inputs were provided by Tim Ingold, who queried common metaphors of learning mediated by environments and social structures. Tim advanced the position that while our educational institutions appear to be changing to keep abreast with new technologies and new lifestyles, fundamental ideas of knowledge as ‘product’ and ideas of learning as ‘acquisition’ - through vertical transfer - remain unchallenged. Tim invited participants to visualize learning as a form of ‘undergoing’, that is, a form of learning which happens through experience and movement. This type of pedagogical approach displaces ideas of learning in set enclosures to open up learning spaces which are geographically and experientially unbounded: “it is an attentional process rather than intentional one; inherently risky because you’re pushing beyond into the unknown”. This view on learning and education calls for a ‘disarming’ of education, with a renovated set of roles and relationships between teacher and students.

Thirdly, Geraldine Mooney-Simmie looked more specifically at curricula in science education. Geraldine pointed to the tension that exists in science education between different understandings of scientific literacy. On the one hand, scientific literacy comprises knowledge of concepts, norms, and practices of scientific disciplines. On the other hand, scientific literacy is also the ability to make decisions about the social impacts of science and be able to recognize strengths and limitations of Western scientific worldview. Drawing on international literature, and focusing on the Irish context, Geraldine recognized that school curricula and assessment systems tend to privilege the first level of scientific literacy.

The day progressed with the provocation offered by Jan. Van Boeckel. An arts-based activity was offered to explore ways of knowing based on sensorial awareness, embodied experience, and memory. Similarly, to the clay-based activity experimented with the commission (Appendix B), the hand was presented as the essential conduit between the body and the environment (see §2.6.3). Participants drew the lines of their hands-on card to sketch out what might be essential features of a landscape, thus representing their hands as a symbolic ‘place’ recounting previous experiences. The activity progressed with participants recalling and sharing personal experiences of being in the landscape of their hands and to listen to and recall the experiences of others (Appendix C).

Commentary
Over the course of the day, participants were invited to share what might be established ideas and new, emerging understandings of scientific literacy. Discussion post-presentations and during the arts-based activity drew out similar themes encountered by the commission on Tuesday:

- Conceptions of knowledge
- Different ways of being in the world
- Ways of knowing
- Awareness of language and discourses
- Real-word experiences
• Teaching and learning
• Power

Comments from the morning pointed to some established notions about the need to provide students with real-life problems; to problematize the role and expectations of science in society through a critical STEM literacy and ‘citizen’ science approaches. In this context technology was mentioned as a means to enhance connectivity and thus empower people, and somehow challenge the verticality of digital transfer of information that was the object of Tim Ingold’s critique. In this regard, a question was raised about the need to incorporate these ideas into teacher education to enable wider awareness. From post-its collecting ‘new ideas’, some people noted they were unfamiliar with contemporary arguments in philosophy of science, such as the triple helix and post-normal science concepts, and specifically the notion of ‘techno-science’ with associated dimensions of uncertainty and ignorance. Across the room, people recognized the gap between new conceptions of science emphasizing uncertainty and scientific discourses based on monitoring and measurement.

In the afternoon, during the arts-based inquiry, participants were stimulated to think further about what knowledge might arise from working in an art form which primarily involves the sense of touch and its value for learning science. The ‘hand’ was introduced both as a part of the body amenable to investigation and a tool for sensing and acting in the world. The hand was thus presented as a metaphor for illustrating a ‘relational way of knowing’ with potentially strong emotional tones.

Some participants experienced empathy, and reported ‘a sudden surge of emotions’ when putting themselves into other people’s’ hand drawings. However, for some participants the level of emotional intensity remained low. Some people declared to be unable to put themselves into somebody else’s storyline. Some others could not link the experience of drawing the lines of the hand with learning in science and did not see any potential link with school science practices they had experienced.

In sum, making science a more accessible subject and increasing young people’s engagement with science were both affirmed, and appeared to be shared by participants. However, participants also recognised that there were new dimensions affecting science, such as complexity and post-normality which required further consideration. Participants found it difficult to consider emotional and biographical dimensions as potentially integral to the learning of science, or understanding of how scientists go about conducting their work. To this effect, the role of the arts, as the commission first identified it, as enabling different ways of being and becoming, challenging power through democratic/playful dialogue, and even encouraging a notion of social justice remained unclear. The experiences in Aberdeen invited further reflection about people’s preparation for arts-based/trans-disciplinary inquiry as well as wider discussions about inclusion and social justice.

3.3 STEAM EDUCATION AND INCLUSION: CAMBRIDGE EXTENDED DIALOGUES

Programme
The Cambridge STEAM event took place on 15 April, 2016 in the Faculty of Education at the University of Cambridge. The specific focus was upon the relationship between ‘STEM subjects’ - as they are currently taught - and the differential access to science and mathematics knowledge affecting groups inside and outside schools (the Commission’s second question). 12 universities were represented and 13 schools and community organisations (Artsbeacon.uk; Bridges Organisation;
Cambridge Science Centre; Education Support partnership; Experience workshop; Historyworks; Ignite; Poetry by heart; Raspberry Pi foundation; Spinney primary school; SteamCo; Tomorrow’s achievers; Educational Trust).

The Event was hosted and chaired by Pam Burnard, a member of the project’s Core Team. More than forty attendees were present at the event, representing a diversity of STEM educators and researchers and STEAM practitioners who work in primary, secondary, tertiary, and community education contexts.

The Morning Session

Laura Colucci-Gray, opened the seminar by providing an overall contextualisation of the BERA Research Commissions, explaining how the Cambridge Extended Dialogues were intended to respond specifically to the project’s second aim: To discuss the role of arts-based, creative pedagogies for inclusive, participatory, and interdisciplinary learning.

Nick Corston (STEAM Co. founder and facilitator) and Rae Snape (Headteacher, The Spinney Primary School) then reported on their productive collaboration to provide STEAM experiences for the children and their families of a local primary school, fostering community creativity through dedicated ‘STEAM days’.

This was followed by Patricia Murphy and Liz Whitelegg (Open University) who discussed how gendered socio-cultural hegemony impacted girls and boys in terms of their perceptions of science, ultimately influencing their interests and perceived ability to succeed in the sciences.

After these presentations, there were Focused Dialogues which considered the following questions:

- How do STEAM facilitators/teachers change (or challenge) dominant discourses about who is good at and has access to or is excluded?
- How do teachers facilitate, empower, or constrain learning?

Next, Cindy Forde (Cambridge Science Centre), Kristof Fenyvesi (University of Jyväskylä; The Bridges Organization), and Carrie-Anne Philbin (Raspberry Pi Foundation) each presented on the work of their respective organisations. Each provided examples of practices to engage children from different communities in interactive and collaborative practices. In particular, digital art making, and creating through experiential, embodied learning practices showed how uniquely combining the arts and the sciences could make their respective subjects of science, mathematics, and digital technology engaging, impactful and available to everyone. The fullness of embodied experience describes the learning space.

In a two-part presentation, Yvette Solomon (Manchester Metropolitan University) first used the familiar TV icon of Lisa Simpson as a provocation to problematize the tendency to caricaturize girls as needing an artistic/emotional approach to STEM subjects. She then presented her narrative research which followed a woman who, during a mathematics PhD, refused to conform to the seeming androgyny of her female colleagues.
This was followed by focused dialogues which considered the following questions:

- How can STEAM practices challenge the binary gender discourses?
- What are the major assumptions embedded within STEAM practice about gender productions which include female masculinity and male femininity in the classroom?
- How far are girls’ imagination and interests harnessed and developed through such events?

Videos of the keynote speakers can be found at [www.steamresearch.wordpress.com](http://www.steamresearch.wordpress.com).

**The Afternoon Session**

Susan Steward (University of Cambridge) initiated a dialogue using video and photo-elicitation stimuli. These were designed to explore issues of gender in the contexts of: (1) ‘Creativity Day’ in a secondary school; (2) Teaching and learning to be an ‘artist’; (3) Depiction of scientists; and (4) PLAY for younger children. Discussion centred on the gender binary and stereotyping images used for marketing that we are confronted with daily. Thereafter, there was table discussion and whole-group discussion on the following questions:

- What do STEAM practices tell us about inclusion/exclusion?
- How is the very focus of inclusive learning conceived?
- How do STEAM practices embody particular, gendered practices?
- How, if at all, does STEAM Education embody inclusivity?

**Commentary**

Generally, participants recognized: (i) widening and deepening the impact of STEAM requires radical reform of pedagogies, (ii) new practices of professional development models to support STEAM educators and (iii) each part of STEAM is critical for the success of the other part. Subjects are intertwined, need new pedagogies, time for teacher collaboration, and new forms of assessment. Numerous other themes were raised during the Cambridge event, including many which pertained to the broad aims of the project initiated in the earlier Aberdeen event. Only the themes which were unique and particular to the Cambridge focus are listed below:

**Gender/Inclusivity**

There is no consensus regarding the specific role of the arts within a STEAM approach to learning, but there seems to be a collective belief in the potential for the arts to promote a more inclusive approach to STEM learning. However, gender inclusivity continues to be a very complex issue which is built around assumptions about what girls are like and boys are like as fixed identities. These assumptions need to be constantly problematized and contextualised.

**Socialisation / Role Models**

To overcome deeply gendered practices, it is necessary to help students identify role models that disrupt and re-negotiate sociocultural expectations of gender, science, technology, engineering, arts, and mathematics. A variety of in-service STEAM programmes will be need to explore the dominant influences in children’s self-perception of their own abilities through changing the shape of educational practice from STEM to STEAM education.
Inclusivity and widening access are highly sought after goals for education. These are areas in which STEAM Education enters the political space. Changes in educational policy are inextricably linked with assessment. STEAM practices, pedagogies and assessment pathways are grounded in the material world inside and outside the classroom but they also need to fit tidily within the current dominant approaches to assessment. The potentials of STEAM Education however would appear to outweigh the challenges. It takes time and care to create a more responsive approach, to consider the possibilities that STEAM education offers for the performance of diverse knowledges, ways of knowing, and ways of being. It also takes time and effort to resist the patterns of thinking which have trained our thought into dismissing ourselves as learning others, as learning selves, as new-STEAM-epistemological sites of learning. Further exploration of such hybrid spaces for learning took place at the third event in Warwick.

3.4 CREATIVE PEDAGOGIES AND PARTNERSHIPS: WARWICK EXTENDED DIALOGUES

Hosted by Jo Trowsdale, the day took place on Thursday 14th July 2016, in the Faculty of Education, University of Warwick. The day focused on the potential of arts-based, creative pedagogies to foster inclusive, participatory, and interdisciplinary learning in science and engineering (the commission’s third key question) and the role of external partnerships.

Programme

Teachers (8), artists (4) and engineers/scientists (3) met at one of four tables with university-based teacher-educators and researchers from across the sciences and the arts (19). Using differently coloured post-its they recorded individual responses, to discuss the appeal, challenge and value of STEAM education-like practices and the significance of partnerships beyond school. These were reviewed at each table and organised in terms of positives, negatives, and recommendations for further research.

In the morning three short project presentations and an activity were offered as provocations to discussion. A display of the three projects and of the artistic, form-finding engineering research work of Wanda Lewis was available during refreshment breaks. The afternoon allowed for more in depth debate of four of the key issues identified in the morning.

1. CREATIONS: developing an engaging science classroom - Lindsay Hetherington and Charlotte Slade, University of Exeter

The presenters shared pedagogic principles developed through the project, and which combine creative pedagogies with inquiry-based approaches to science education. These underpin the planning, and approaches for teaching and learning science, being trialled by project partners in 11 EU countries. (http://creations-project.eu/about/). A newly developed, planning wheel was offered as an example.

To exemplify the arts-science relationship, and to provoke responses, eight participants were facilitated to build a ‘human table’. The activity required a willingness to trust and collaborate, combined with the innate engineering and chemical energy of the body (see the website www. steamresearch.wordpress.com for a visual account of the activity).
2. The Imagineerium - Jo Trowsdale, University of Warwick and Jane Hytch, Imagineer Productions
The Imagineerium, unlike CREATIONS initiation by science partners, was developed by a cultural organisation working with engineers, civic and education partners. Pupils, aged 8-10, work in teams with the support of artists, engineers, and teachers on a commission to imagine, design and make a moving model for performance, at a site-specific event. The project advances a practice-based model for learning, drawing upon imaginative, embodied and arts-based, approaches to learning (http://www.imagineer-productions.co.uk). Teachers from 5 primary school partners were involved in the day.

3. GET-WET – Pat Thomson and Andy Townsend, University of Nottingham.

The University of Nottingham and Papplewick Water Pumping Station, designed this project as a child-led enquiry into a ‘big’ and cross-disciplinary question: ‘what interests us about water?’ Science educators and artists, in movement, theatre, visual and words, worked with teachers in 5 schools (3 secondary, 2 primary) to enable children to investigate their questions. The approach engaged students in and beyond science; with local history and environmental issues. The arts supported learners’ engagement with understanding scientific and mathematical concepts, and with exploring issues arising at the intersection between science, technology, and society.

In the afternoon, participants pursued the following questions identified as the dominant questions from the morning:

- What is the purpose of steam education?
- How do perceptions of science change through steam education?
- How could ‘design’ provide a methodology for steam education research?
- What kind of CPD is needed for teachers to deal with steam pedagogy?

Commentary

Discussion drew on themes first identified in Aberdeen:

- conceptions of knowledge
- ways of coming to know
- ways of being and becoming
- learners / learning
- teaching and learning
- distinctive role for the arts
- real world experience
- social justice

The Human Table activity provoked discussion on the potential for arts-based, creative pedagogies to open up how learners learn beyond specific curriculum subjects and what might be a distinctive role for the arts in STEAM. Whilst biology and engineering were apparent in this embodied structure, observers and participants reflected other ideas. The appeal and value of embodiment in learning and knowing, and the importance of collaboration in learning were strong messages across all presentations and discussions. The discussions noted that when science education alone is the starting point, the arts can be positioned to play an instrumental role and a reciprocal relationship is
prevented. If approached in a less subject focused way, the creative processes of art-making can be woven into science and children can be positioned as makers, connectors, and learners. Morning discussions recognised a significant appeal for what is termed STEAM education. Its value was noted in terms of motivating and aiding learning in science; in part by revealing the significance of science in daily life. However, most comments related to the role of STEAM in extending beyond science, connecting it to human issues, expanding pedagogic models, including recognising the role of the body, and thereby re-imagining what education might be. The collaboration of disciplines was a positive and desirable move, emphasising skills and allowing the possibility of inter- and trans-disciplinary learning. The arts in STEAM for many denoted ‘arts and humanities’ as well as an expansion of ‘cognition’: to embrace visual and physical (knowing how as well as knowing that).

The current emphasis upon separate, siloed disciplines in a knowledge-based curriculum and related outcome based accountability which ignores process, were the key challenges of developing STEAM education. Echoing recommendations from the literature review, participants identified that research ought to:

- expand the understanding of creative pedagogies;
- clarify and communicate the varied conceptions and models of STEAM education and what kinds of knowledge and learning is promoted through them
- evidence the value and benefit of STEAM-like approaches (against extant and broader than subject criteria)
- trial and evidence professional development conceived to promote inter-disciplinary practice

An urgency was given to these points given the resource challenge which was identified repeatedly. All participants recognised the time, cost and expertise required for teachers to plan and work across disciplines. This included the professional development investment needed to develop the confidence and expertise of staff to work in more open, ‘might be’, science-arts rich ways, using approaches which shift agency for learning to children. Whilst the projects shared were inspirational, their scalability to change core practice and their limited engagement with secondary schools was noted.

3.5 STEAM AND RURAL COMMUNITIES: WALES EXTENDED DIALOGUES

The debate in Wales was captured asynchronously in three ways, and primarily with practicing teachers. Initial scoping did not identify any organisations articulating their work as distinctively ‘STEAM’, and teachers did not identify any external groups or their own practice as ‘STEAM’. Rather, terms such as ‘creative’ - approaches, practices - were used, and especially in relation to the use of technology within science lessons. A general online survey was designed to gather respondents’ views on STEM and STEAM education and gained ethical consent from the University of Aberdeen. This was publicised through contacts, university email addresses for teachers, and via the Workforce council over the May-July period. However, perhaps due to the timing of the publicity, the survey had a very low response rate. Discussions were also held with newly qualified and experienced teachers, across phases and subject areas, who were involved in a nationwide CPD activity unrelated to STEM/STEAM. As in the initial scoping activities, the term STEAM and the debates that it fosters were not generally recognised. Teachers who taught science (in the primary or secondary phases) did, however, recognise aspects of their practice sharing characteristics with STEAM projects. These tended to
be what they identified as ‘creative’ approaches, or use of storytelling, or digital technologies. Of particular note was the use of Pie Corbett storytelling pedagogies in developing the non-fictional writing of science reports in primary schools. Discussions were also held with experienced advisors and advocates for arts-based education in Wales. They reported some work on the links between numeracy and arts-based pedagogies in the light of the Smith (2015) report and funding from Arts Wales. However, this concerned a very small handful of schools across Wales (less than 9), and none of these projects were identified as explicitly engaging with the STEAM agenda.
4. DISSEMINATION SESSIONS

As we progressed towards the end of the project, we continued to test the pedagogic potential of STEAM drawing on the variety of educational perspectives and affordances of different policy contexts across the UK and Internationally. Three further dissemination sessions took place respectively at the BERA Conference in Leeds in September 2016; at the launch of the Curriculum Network in Stirling and as the BERA invited symposium at the New Zealand Association for Research in Education Conference in November 2016. All three sessions enabled the review to be extended by including educationalists’ responses to STEAM through different approaches, as described below.

4.1 INNOVATION SESSIONS: LEEDS AND STIRLING

The innovation sessions organised at the BERA Conference in Leeds in September 2016, and subsequently in Stirling in November, explored the idea of STEAM as a multi-disciplinary and multi-vocal, pedagogical construct arising at the intersection between different disciplines. As part of the conversations, we sought to invite people to reflect on different conceptions or configurations of STEAM, surfacing different conceptions of knowledge and recognising how such conceptions may originate from different disciplinary positions. After a brief introduction on the different and contested political discourses behind STEAM education, participants were introduced to different draft aspects of the review: the search for conceptual clarity as it may be common in philosophical research; acknowledgment of complex relationships as it may be common in some areas of the sciences, such as systems biology and ecology; understanding of different traditions of inquiry based on the integration of the arts. Drawing on the experience of ‘making a human table’ enacted at the Warwick event, participants were invited to reflect on the pedagogical value of an art-informed pedagogy and subsequently to create their own, theoretical, and practical, configurations of STEAM using a set of foam coloured letters.

Responses from participants at both events, reflected the same level of surprise to the ‘making of a human table’ activity. In ways similar to the event in Warwick, the activity gave the opportunity to reflect on the transdisciplinary nature of experience and the value of looking through different disciplinary lenses to uncover opportunities for enhancing pupils’ understanding. Interestingly, when we asked participants to expressly say what they were seeing, all resorted to different metaphors, indicating their prior backgrounds and educational concerns, but also expressing value positions about relationships, how people learn together or how disciplines can come together. For example, metaphors such as ‘ensembles’, or ‘umbrellas’ were used as well as more structural ideas such as ‘bridges’ and ‘scaffolding’ to refer to curricula.

The activity allowed participants to be ‘playful’, identifying configurations of words which expressed purposes, identities and ideas. The activity invited people to let their thinking about practices unfold. Such a position on knowledge offers the opportunity to explore multiple possibilities as well as comparing one’s experiences with those of others. However, further reflection needs to be given to
the value and significance of these activities in the different contexts. The BERA innovation session, located within the Creativity strand at BERA, attracted participants with the desire to engage and to explore in discussion around STEAM, and what it might bring to research and practice. Conversely, the session in Stirling attracted a more varied audience who also indicated, as per the event in Aberdeen, a certain level of unfamiliarity with the concept of STEAM. While the Scottish Curriculum for Excellence has embraced a wider agenda that focuses on knowledge and skills, including interdisciplinary learning, plenary discussion pointed to the need for further analysis of the role of STEM subjects and their interfacing with other subjects in the curriculum. Equally, there remains a certain ambiguity as to which skills are being valued and foregrounded in the curriculum, beyond conceptual thinking to include more creative, linguistic, relational, emotional and practical dimensions.

4.2 SYMPOSIUM: NEW ZEALAND ASSOCIATION FOR RESEARCH IN EDUCATION CONFERENCE

Reviewing, re-visioning, and re-enacting: a STEAM education fit for the 21st Century?

Papers:

1. STEAM education: hot topic, hot water, hot air or hot house? Richard Davies.
2. Re-positioning and re-visioning science education. Laura Colucci-Gray.

The first paper, a philosophical perspective, reviewed the meanings of different conceptualisations of STEAM education, as evidenced in the literature reviewed. The paper explored the roles of these meanings in different STEAM discourses. The second paper, from the perspective of a scientist, science educator and ecologist, explored the implications for education of a relational approach to science: one which situates the learner as a person deeply connected to all aspects of the world. Science education is thus a process for deepening one’s awareness of the connections and interdependencies between oneself and the natural world, involving multiple ways of seeing. The final paper, situated in the arts, argued for an emphasis upon art-making as a process, rather than ‘the arts’. It suggests that educationalists might capitalise upon the embodied, symbolic, relational, and collaborative qualities which characterize many models of art-making to enrich the sciences. This might feed a new re-visioning of the arts, sciences, and humanities as interconnected.

Responses from the floor suggested that the New Zealanders were less exercised than the UK by the dilemmas of STEAM, although they recognised a focus upon ‘teaching content’ to improve outcomes in science, which might affect international standing. The New Zealand science education symposium, which followed ours, was characterised by presentations of active, situated and community connected practice. Several factors appeared to be at play here. Firstly, the strong community bonds of a Maori culture, suggested a connectedness of learning to place and others as a default position. It is also worth noting here the importance of bi-culturalism for New Zealand and New Zealand schooling. New Zealand as well as Canada and Australia have a stronger tradition of critique of educational models privileging Western worldviews over indigenous traditions. In these contexts, frames of complexity and post-normality (presented in §1.1), while contested and certainly very different from indigenous traditions, may be worthy of further attention. Secondly the competency-based curriculum in New Zealand which aims to grow ‘confident, connected, actively involved, lifelong learners’ provides a strong context to debate the significance of knowledge development and has provoked thoughtful
review of what and how assessment of learning and competence happens (Hipkins, 2007; 2009; 2013). Thirdly the recent emphasis upon teachers as researchers, supported by a Teacher-led Inquiry Fund has strengthened the reflective practitioner model and appeared to be generating both appetite for and confidence in developing teaching and learning through practice-based research.

Our host and respondent Rose Hipkins, saw the arts as a useful frame for provoking broader educational debate. Indeed, she used the question we asked our, primarily science educator, audience – ‘why might you want to engage with the arts?’ – with an audience of tertiary science teachers the week after the symposium and was heartened to see that developing content knowledge was the least valued reason, with broader relational factors being the stronger arguments.
5. CONCLUSIONS

This review has considered the body of literature on changing conceptions of science, forming the backdrop of a review of the emerging body of literature in creative and arts-based approaches in STEM subjects. Attention was focussed on the purposes, values, and possibilities that they may offer. We have engaged with a diversity of stakeholders’ views and understandings, bringing in teachers, academics, arts and STEM practitioners and educators. It sought to uncover areas of significance for educational research across the four nations.

Key ideas and recommendations are housed in the executive summary at the beginning of this report (pp. 7-12), but here we share our summative reflections on the three distinct and interrelated aspects which framed the commission. First, conceptual clarity is a prerequisite of future research. Second, that the apparent dominant drivers for STEAM, may give rise to significant educational possibility in terms of twentieth century skills; and third, interesting avenues may lie with the provision of a platform for modelling inclusive pedagogies for the future, together with reflexivity in practice and in research. Below, we note key findings across the three areas.

1. Changing conceptions of knowledge across sciences and the arts
The review has noted a range of conceptualisations of arts and science. These are framed in terms of: (i) different epistemic principles; (ii) different expectations of the relationship between science and society, and ideas of nature; and (iii) different expectations of the role of STEM education in schools. The literature showed a variety of educational practices and approaches but lack of consistent and explicit engagement with epistemological debates or positions. In setting out this report (§ 1.1), we noted several areas of contestation which inevitably limited the specificity of any conclusions that can be drawn in this exploratory review. We do, however, suggest further work is needed on theorising practices and exploring the philosophical implications of contemporary debates in and across sciences. Emerging from the Extended Dialogues with stakeholders, we note limited consideration of: values and context in science education; the apparent conflict between cognitive and embodied approaches to education; and theoretical critiques of science as a contested field. Such limitations prevented further exploration of the pedagogical potential of STEAM. In particular, it limited exploration of the role of the arts as potentially enabling multiple ways of seeing, ways of knowing and ways of relating with others and with the natural world.

2. The relationship between formal and informal science education and differential access
The review noted three, significant factors shaping the teaching of science in schools. The first relates to the differential access available in diverse geographical areas. The second is that informal, or project-based, learning appear to offer some fruitful examples of STEAM education. The third is that, approaches deemed successful in responding to gender and class inequalities in science education, also appear to share characteristics with the ambitions of STEAM education.
The Extended Dialogues emphasised a tendency for STEAM education initiatives to be driven by a limited number of local, charitable organisations and academics interested in its development. These endeavours appeared to be more prevalent in post-industrial settings. Both in Cambridge and at the Warwick event, discussion included new practices emerging with the broad purpose of engaging children and communities with science. These practices drew on significant partnerships between formal and informal sectors. However, it also indicates that there is an uneven distribution of opportunities for children to experience STEAM education across the four jurisdictions. This effect may be traceable to available resources, but also to the different ways in which schools are organised and regulated across the different areas in the UK.

There is a plethora of research and evidence concerning the issues of gender and class inequalities in science education, and the uptake of science in the post-compulsory phase. The Extended Dialogues featured discussions of characteristics of STEAM practices, their aspirations, and need for further research. Themes included: the role of values, identity, embodiment, and creativity in STEAM practices. While there are commonly held perceptions that the arts can provide a space for open inquiry, facilitate inclusivity and invite re-framings of STEM, evidence is still limited. Debates on conceptions of science at the intersection of language, gender, ethnicity in science education, continue.

3. Arts-based and creative pedagogies: fostering inclusive, interdisciplinary learning

Analysis of the literature identified examples of the use of creative approaches to support conceptual thinking in science and science education. However, creative approaches to science education do not clearly articulate with the extensive potential of arts-based, creative pedagogies.

The review identified the need for further clarity about the role of creativity in science. In fact, the lack of clarity about what is signified by the terms ‘art’, ‘arts’ or ‘creative’, challenges any strategic advance of arts-based and creative pedagogies for STEM education. Additionally, the precise role of role of arts-based and creative pedagogies can only be known when we have greater understanding of what conceptions of science in society are desired in education. The choice of pedagogy is shaped by, and shapes, what is understood.

Even recognising the definitional challenges around the arts, and creativity in education, it was clear that the STEAM education practices profiled through Extended Dialogues reflected and drew upon accepted notions of the democratising character of the arts. Both the collaborative, participatory character of practice in the performance arts and their potential to offer agency and critique, to nurture and embrace children’s personal and subjective perspectives, was noted as significant in the design of these projects and practices. Arguments for the potential of inviting and embracing diverse experiences, voices, and different ways of being and knowing were recognised. These pedagogies, which prioritise self-expression, collaboration, and dialogue as emergent could find their place effectively in dealing with contemporary science issues, where facts and values are contested. However, here, as in the literature exploring art-based approaches to learning science, the practice-based evidence is limited.

It was noted by participants that curriculum hierarchies and assessment, the obvious challenges to interdisciplinary practice, were not the only barriers. The affordance of time is essential to support and
enable teachers to forge interdisciplinary practices. Nonetheless, there was great interest expressed in the ways in which arts-based practices introduced disruptions and alternative ways of approaching science. There was evidence of the role of the body in learning, such as learning science or math through movement. These approaches were not widely known, but were seen to advance the value and characteristics of inclusive, interdisciplinary learning.
Several recommendations are identified in the executive summary (sited at the beginning of this report) for further interrogation of the value and extent of possible pedagogies for STEM/STEAM education. Further to this, we offer here a set of plausible and practical approaches to the development of STEM education; from pedagogical improvements in terms of motivation and access to science education, through to enabling learners in different phases of education and teachers, to gain a more critical engagement with science. We suggest that more research is needed to support curriculum reform and pedagogic innovation. This could be effected within a framework of evidence-based teacher inquiry to be introduced at teacher education level. The Donaldson Review presently in place in Scotland with a focus on teacher education, and the Donaldson Report in Wales have inspired such local, professionally lead experimentation. A ‘STEAM’ pedagogy can inform primary, secondary, and tertiary education to promote the values of developing creative pedagogies for 21st century learning.

A commitment to all educational recommendations listed at the beginning of this report requires extensive research programmes into STEAM education. This would include systematic research, extensive mapping, impact studies, and action-research of STEAM projects. Educational research ought to work with teachers and policy makers to develop these local experiments in ways that enhance and broaden curricula, enabling the possibility of a more dialogic and dynamic engagement with partners in STEAM practices.

We recognise that, in addition to teacher-led pedagogical enhancement, there is a need for collaborative professional development. Teachers should be encouraged to become involved in local networks either within or between schools, and to facilitate school development days for STEAM education through creative, inquiry-based and critical pedagogies. Consideration ought also to be given to including these ideas and debates more fully in initial teacher education, induction teacher learning and in-career teacher learning. With the current surge of interest in STEM education worldwide, we envisage scope for further, innovative research in the field. Potentially, STEAM-like practices may also be extended to training of future researchers and professionals in Higher Education.
Reviewing the potential and challenges of developing STEAM education through creative pedagogies for 21st learning: how can school curricula be broadened towards a more responsive, dynamic, and inclusive form of education?

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Publishers.


### 8. APPENDICES

#### APPENDIX A. THEME-RHEMES DOCUMENT

<table>
<thead>
<tr>
<th>Conceptions of knowledge(s)</th>
<th>What are conceptions of knowledge in relation to STEM/STEAM? To what extent should they be challenged (canonical knowledge to something else) and made explicit?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ways of being</td>
<td>How do STEM/STEAM relate to individual and collective identities; multiple ways of being in the world?</td>
</tr>
<tr>
<td>Ways of knowing</td>
<td>How do STEM/STEAM enrich, challenge, embrace or promote ways of knowing; What are the embodied forms of knowing? How does STEAM create distinctive and particular (inter-) textual, exploratory spaces of thought and action; or/and a non-verbal, artistic narrative or embodied engagement, understood in new /distinctive way specific to STEM/STEAM?</td>
</tr>
<tr>
<td>Ways of being and becoming</td>
<td>How do STEM/STEAM contribute to personal and professional identity (being a scientist, being an engineer, being a technologist, mathematicians) selfhood/personhood?</td>
</tr>
<tr>
<td>Learners/Learning</td>
<td>What is meaningful? To what extent does literature give emphasis on what is ‘meaningful’ for the learner? See literature on embodiment? Reframing of the disciplinarity? Boundary crossing and transitions between home, world and school? How does STEM/STEAM change/ contribute to the fund of knowledge/skills and understanding of the C21st learner?</td>
</tr>
<tr>
<td>Awareness of language and discourses</td>
<td>What practices and theorisations are enabling/provoking shifts in paradigms, mindsets; behaviours? What is the role of the arts in enabling new discourses and languages of learning; What are the other elements of the arts that take us outside of language?</td>
</tr>
<tr>
<td>What is distinctive and characterizing role of the ‘Arts’</td>
<td>Does bringing in the arts into STEAM invite disturbance? Does it discourage/address negative ‘hot-housing’ and elitism (artists/artistry); (how/when) do the arts legitimate STEM? When do the ‘arts’ enable agentic/playful/democratic? What defines the</td>
</tr>
<tr>
<td>Social justice</td>
<td>What role can STEM/STEAM play in challenge inequalities? And how does the debate entrench inequity? Where is evidence of inclusive curriculum practice?</td>
</tr>
<tr>
<td>----------------</td>
<td>-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Real-world experience</td>
<td></td>
</tr>
<tr>
<td>Power</td>
<td>How do children/engage with STEM/STEAM and the relevance to their life? Does it matter if it isn’t recognized as STEM/STEAM What evidence is there of dominance/To what extent is the dominant knowledge made transparent and exposure of marginalized; Does the western liberal model have better explanatory power than other models of science? For example, can we work/engage with indigenous knowledge?</td>
</tr>
<tr>
<td>Looking forward/looking</td>
<td></td>
</tr>
<tr>
<td>back</td>
<td>How do we come to this place with knowledge of structure? Historical patterns? Have we have any feasibility of STEM/STEAM across educational sectors? Gathering case studies of STEAM practices? Open-ended experimentation and what’s going on? Where are critical points where STEM/science/math ‘anxiety’ hits? How do we disturb the system and sustain change? (go beyond one-offs)</td>
</tr>
<tr>
<td>Trans-literacies and</td>
<td></td>
</tr>
<tr>
<td>semiotics</td>
<td>How is the performance of STEM/STEAM in society, made visible through arts practice? Is there a semiotics of learning and performance/display of the cultural symbols of STEM/STEAM? How can we come to see behind these constructions; How/are these embodied forms of knowing trans-literacies?</td>
</tr>
<tr>
<td>Teaching and Learning</td>
<td>What is the significance of socially-committed arts and science practice? Is this a lens or a framework? How does STEAM pedagogic practice characterize something new for education? Does the art give visibility to socially-committed and culturally-appropriate practice?</td>
</tr>
<tr>
<td>Reflexivity</td>
<td>What evidence is there of environmental and global connectivity? How is the context and positioning of STEAM in society?</td>
</tr>
</tbody>
</table>
APPENDIX B. MOULDING ONE’S OWN HAND IN CLAY, WITH THE EYES CLOSED

Jan van Boeckel, March 2016

The design of this group activity, lasting for about an hour, is rather basic, yet its impact often turns out to be profound for those who partake. A group of participants gathers around a table, each having two balls of rough clay in front of them, both having the size of a grapefruit. One of the balls will serve as “raw material”, while the other will form the basis, the sculpted hand palm, to which the other parts of this organ, the fingers, will be attached, step by step. The first task, still performed with eyes open, is to knead a “hamburger-like” form out of one of the clay balls and to position this flat surface on the table right in front of them. Then the participants are asked to close their eyes for the duration of the activity and to work in silence. As the facilitator I guide them through the stages of the process. I invite them to open the hand that they normally do not use for writing and drawing; this hand will be their reference – the original that they will now “copy” in clay. They cannot see it, but with their other hand they can sense some of its outward characteristics. Only through haptic perception can they inform themselves of the size of its different parts, such as the palm and the fingers. I invite them to first attend to the palm of their hand with its life lines and to feel where it goes up and where it goes down, where it is hard, bony and muscular, and where it is soft, as if it is a landscape with hills and valleys and rivers running through it (Figure 1).

Figure 1. Artist’s hand, 1941. Axel Poignant (1906–1986), England. National Gallery of Australia, Canberra

Subsequently, slowly and one after the other, the fingers are formed and connected to this palm, starting from the little finger. I ask them to feel the different parts and joints that each finger consists of, and when they connect clay finger to clay palm, to be conscious of them being part of one organ and to also pay attention to the negative space, the spaces in-between the distinct parts. All the time they “scan” one of their hands with the other hand, in order to receive information on how to proceed in the further careful ongoing modelling of a sculptured hand.
At the time when the stretched out, “receiving” clay hand is finished, the participants are encouraged to cross a defamiliarizing threshold. Now I ask them to gently pull up all the clay fingers so that they touch each other at their tips, thus expressing together a new gesture. When this is completed, this first part of the activity is finished.

It is important to underline that a clay sculpting session is not confined to the artmaking part where participants have their eyes shut; the reflective group dialogue which immediately follows is as much part of it as the actual moulding of the clay.

One of my interests in developing this activity was to see if such a hands-on workshop affords for new and creative ways to register one’s immediate environment; whether or not the sensory-based task of sculpting part of one’s own body with closed eyes enhances the participants’ ability to engage with place, with and through their bodies. Is there a dialogue going on between the supposed internal (the corporeal and anatomic) and the external (the environment) as poles in a continuous process of exchange between body and place?

For anybody participating in this it is quite an overwhelming experience, to finally see the clay figure one has made. All clay hands are put in a circle in the centre of the table and we talk about how the results look and what the impact of the process was. Now participants take a first look at the results of the others as well. Often there is a bit of laughter, and other expressions of excitement. I then start out by asking some pointed questions, which I try to keep as open-ended as possible. Often I begin by inquiring: “How was it?” And then slowly a conversation evolves. Finally – and this marks the end of a clay hand making session – I try to shift the conversation to what they think they’ll bring home from the experience. I am interested to hear if they make some wider connections.

Of course, when doing this, both of one’s hands get rather clayey from working with this plastic and granular material. Interestingly, however, in the process, the clay hand starts to acquire about the same temperature and “feel” as the body, and the same balance of dryness and moistness as a human skin would have upon touch. At times, a participant gets completely overwhelmed by the sensation of suddenly (mis)taking the clay hand to be their own real hand – for a moment they could not tell them apart.

The immersion in and surrender to the activity seems to evoke new ways of engaging the senses and to stimulate the imagination in unforeseen ways. By encouraging participants to approach phenomena indirectly instead of head-on, by inciting them to “think” with their hands and spurring them to expand on the affordances that the crude materials they work with allow for, they encounter openings to new and direct experiences.

One purpose for this activity could be to create a pedagogical setting in which environmental or science education is initiated from an open-ended, art-based, direct and embodied experience. As such it, affords a basis for educators to encourage participants to subsequently seek amplification and further elaboration of the experience. One way to do this would be by exploring some of the anatomical and also cultural aspects of the hand and its immanent relationship with the rest of the body. A starting point could be the following observation by Gregory Bateson:
You have probably been taught that you have five fingers. That is, on the whole, incorrect. It is the way language subdivides things into things. Probably the biological truth is that in the growth of this thing – in your embryology, which you scarcely remember – what was important was not five, but four relations between pairs of fingers. (G. Bateson, cited in N. Bateson, 2010)

As a philosophical basis for it one could think of Merleau-Ponty’s (2002) suggestion that our body should be conceived of as our means of communication with the world, rather than merely as an object of the world which our transcendent mind orders to perform varying functions. When one of our hands touches the other hand, it represents the body’s capacity to occupy the position of both perceiving object and subject of perception. A continuous oscillation takes place between the two, back and forth. In Merleau-Ponty’s own words: “when I press my two hands together, it is not a matter of two sensations felt together, as one perceives two objects placed side by side, but an ambiguous set-up in which both hands can alternate the role of ‘touching’ and being ‘touched’” (Merleau-Ponty, 2002, p. 93). The body is capable to be both sentient and sensible, yet touching and touched can never fully coincide. For Merleau-Ponty, incarnate consciousness is the central phenomenon of which mind and body are abstract moments. The body tries to touch itself while being touched and initiates a kind of reversible reflection. In this, the awareness of what it feels like to be touched encroaches on the experience of touching. Our embodied subjectivity is fundamentally in the intertwining of these two.

Reflections from facilitator, Jan Van Boeckel

The activity was hosted in a different space from the room in which we had earlier meetings, effectively a “science lab”, where we could work with raw clay.

To me, as the facilitator of this artistic process, it meant that I had to assess at the spot what kind of workshop this space, and the allocated time for it, would afford. At the final moment the clay fingers are to be taken up so that the fingertips of clay would touch each other, and all this is done with closed eyes. When ready, everybody opened their eyes again and attended for a moment to their hand represented in clay. In the ensuing open-ended conversation, we focused on the meaning-making that happened for each participant in and through the participation in this activity. To me, as facilitator, this open-ended structure was expressive of the idea that meaning-making through artistic process moves away from knowledge transfer and can represent a way of coming to knowledge that stems from direct, hands-on experience in the here and now. As such it also depends on and has implications for the ability of the facilitator to “hold this space”.

An additional dimension is that such a way of engaging with a non-purposive process of which the outcomes are singular for each and every participant can be seen as being expressive of “holding out with ambiguity, uncertainty and not-knowing”: that form of learning that we may want to encourage when we think of creative pedagogies for the 21st century: finding ways to cope with its states of extreme flux and dynamic change as some of its characteristics.

In a similar vein, it provided a heightening of our presencing to the activity and to our collaboration with our co-participants through engaging our sensory perception, our corporeality and
proprioception directly in the process - elements which Tim Ingold has referred to as “thinking through making”. Additionally, the circumstance that for a certain period of time we sat in a circle around the table facing each other, with hardly any laptops or phones between us to fragment our attention, contributed in my view to the overall animated quality of the dialogue.”


APPENDIX C. THE LINES OF THE HAND

Jan van Boeckel, March 2016

An important question in the context of thinking about sustainability is how we relate and feel connected to places in the natural world, to landscapes. This relationship, however, may undergo deep changes in different phases of one’s life. The felt bond, at any moment, is partly informed by prior experiences and shaped through our memory. What do we carry with us as a “storied remembrance” of places we have been before and the sensory perceptions we have felt there? And can such places in nature and “memories of the senses” be evoked through art and imagination?

The lines of the hand activity is about engaging the imagination as fully as possible, and the point of departure is merely a pencil drawing of someone’s palm lines on a white piece of heavy cardboard. This uncommon circumstance, of using very basic materials and a theme related to one’s own body, makes the activity at once more intimate and personal. We see the lines on the palm of our hands every day but we seldom really pay attention to them.

The lines of the hand activity challenges the participants. Can imagination help them to feel a sense of re-connection to nature? Could this ability facilitate their capacity to retrieve what they carry as memory of place along with them from childhood onwards (while they themselves may not be necessarily aware of this)? This artful activity is basically an effort of introspecting one’s memory of sense of place. Ideally, it also provides space to talk about the differences between fantasy (taken as a pure mental construction), imagination, and visualization in the mind’s eye. Lines of the hand consists of the following stages.

Introduction
As main facilitator of the activity, I will start out by pointing out that this workshop will be about our embodied knowledge: our sensorial perception, our memories and our imaginative capacity. I am interested to see what happens when we look at imagination not as a tool of our will, but as a mode of engaging with and of relating to the world in a following mode rather than in an intentional (purposive) way.

Drawing the lines of one’s hand
Each participant is invited by me to make a (not too detailed) pencil drawing of the main lines on the palm of one of their hands. To make the drawing, they should use their unschooled non-writing hand. The reason for using the “wrong” hand is to cause an estranging, defamiliarizing effect and to
Reviewing the potential and challenges of developing STEAM education through creative pedagogies for 21st learning: how can school curricula be broadened towards a more responsive, dynamic, and inclusive form of education?

direct the focus to the lines of the one hand that is most predominant in our everyday actions. It is important that the participants don’t spend too much time on the drawing, as the lines shouldn’t be too elaborate and detailed; the sketchier they are the better.

Forming small groups
Here the participants are asked to form subgroups consisting of four to five persons each. Within each small group they exchange the cards, so that each participant has the hand line drawing of somebody else. Each subgroup appoints one member to specifically report later to all the participants on what has come up in their specific subgroup. Before the subgroups split apart, participants are asked if they can try to experience themselves as being in a landscape, a landscape that is formed by the lines on the paper (the hand lines of another participant). They should try to feel the different sensory experiences that being in this landscape seems to bring along. This can be a memorized place or landscape, but also something that comes from the imagination completely. Then the subgroup finds a quiet space for itself.

Focussing on the drawing of the lines
The participants of the subgroup spend some minutes meditating on the drawing of rather abstract lines each of them holds in their hands. Subsequently, the members of each small group tell each other of how it is to be in this imagined territory, one after the other, until all have had their turn.

Reporting in the bigger group
When all small groups are ready, the facilitator asks them to assemble again together with the others in the larger group, forming a circle. Here, the reporters are invited to share with the others what took place. The facilitator leads this conversation. What were the kinds of sensory experiences that the participants talked about in their group? Which ones came up first? Which were easier to describe, and which ones more difficult? Was there a difference between participants who talked about themselves as being inside a landscape and those who looked at it from a distance?

Returning the lines of the hand drawings to their makers
The facilitator then asks the participants to request their respective partners in the exchange to return to them the card with their own hand lines.

Haiku poem making
The idea is that the participants take their own hand line drawing along on a short walk in the local area in search of a physical spot in the area that would, in some way, “resonate” with the drawn lines on their card. They should look for some kind of resemblance in patterns. Once found, this resonating part of the environment is their location, where the facilitator invites them to write a haiku-like poem. In this short poem they should try to respond to the “gift” they’ve received of one of the other participants trying to imagine him- or herself as being in a landscape formed by one’s own hand lines. When a participant has finished composing the haiku, he or she then returns to the large circle of whole group together. The poems are read out loud (but only if the maker would voluntarily choose to do so, there is no pressure). If time allows, we have a group conversation on how this activity makes sense (or doesn’t make sense) in the context of the engaging with the issue of sustainability.
## APPENDIX D: TEMPLATE FOR LITERATURE SEARCHES

### Frame for STEAM Literature Review

<table>
<thead>
<tr>
<th>Questions?</th>
<th>Supplementaries</th>
<th>Key words</th>
</tr>
</thead>
<tbody>
<tr>
<td>How did the terms (STEM and) STEAM come into usage?</td>
<td>Why? What lies behind their introduction? How widespread is their usage?</td>
<td>STEM STEAM</td>
</tr>
<tr>
<td>What are the changing conceptualisations of science? Which are dominant and well discussed (and by which disciplines) and which are marginal (under researched) (and by which disciplines)</td>
<td>What is the concept ‘science’? How does our definition of science relate to STEM? Is this definition defensible and widely shared?</td>
<td>Science and society; science in society; Science and nature;</td>
</tr>
<tr>
<td>What is the relationship between science education and conceptualisations of science?</td>
<td></td>
<td>Science education; Philosophy of science</td>
</tr>
<tr>
<td>Is there any literature relating the changing conceptualisations of science to changing conceptualisations of arts (or vice versa)?</td>
<td></td>
<td>Arts in science; science and arts; science and music; science and theatre</td>
</tr>
<tr>
<td>What do we mean by formal school science? What are the key principles of formal school science? How differently are these conceived across the 4 nations?</td>
<td>What dominant conceptions of content, pupil-teacher roles and the pedagogical relationships between each (and the variance)</td>
<td>Science curricula; science assessment; instructional learning and science; science classroom practice</td>
</tr>
</tbody>
</table>
Reviewing the potential and challenges of developing STEAM education through creative pedagogies for 21st learning: how can school curricula be broadened towards a more responsive, dynamic, and inclusive form of education?

<table>
<thead>
<tr>
<th>Frame for STEAM Literature Review</th>
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<tbody>
<tr>
<td><strong>Questions?</strong></td>
</tr>
<tr>
<td>What examples are there of pedagogical practices in science which foster democratic learning: particularly inclusive or participatory or interdisciplinary learning? Do any of these link explicitly to conceptions of arts and/or conceptions of science?</td>
</tr>
<tr>
<td>What is the evidence for differential access to science knowledge? Which groups are identified? What are the key barriers to access? Are these common across groups (what is the variance)? Are there commonalities across different groups? (and variance)?</td>
</tr>
<tr>
<td>What are the changing conceptualisations of arts? Which are the dominant and well-discussed forms and which are marginal? (in the curriculum and in research)</td>
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</table>
### Frame for STEAM Literature Review

<table>
<thead>
<tr>
<th>Questions?</th>
<th>Supplementaries</th>
<th>Key words</th>
</tr>
</thead>
<tbody>
<tr>
<td>What is the relationship between arts education and conceptualisations of arts?</td>
<td>What evidence is there for the arts / particular art forms as learning media? What conceptualisation of arts is signified by the ‘A’ in STEAM?</td>
<td>Arts education; community arts; participatory arts</td>
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<tr>
<td>What do we mean by learning? What counts as having learnt something? How are teaching and learning related?</td>
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<td>What distinction is drawn by the term learning ‘inside and outside school’?</td>
<td>What characterises formal, informal, community based learning models?</td>
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<tr>
<td>What do we mean by arts-based, creative pedagogies? What examples exist in the literature? What are the key advantages of such approaches? What are the key weakness? What are the key issues in their implementation?</td>
<td></td>
<td>Arts and inclusion; Arts pedagogies; creative pedagogies; Drama as a learning medium</td>
</tr>
</tbody>
</table>
Frame for STEAM Literature Review

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<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>What examples of STEAM education exist - professional, HE FE schooling?</td>
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<tr>
<td>What arguments are advanced for STEAM education?</td>
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<tr>
<td>What do these seem to have in common?</td>
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<td></td>
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<tr>
<td>What organising principles can be identified?</td>
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<td></td>
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<tr>
<td>Can we identify what constitutes STEAM education</td>
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<tr>
<td>What issues are evident?</td>
<td>The challenge and costs of partnership / collaboration; school change drivers; practice innovation</td>
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<tr>
<td>What are the issues documented about making STEAM learning happen?</td>
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</tbody>
</table>
APPENDIX E: PARTICIPANTS ATTENDING EXTENDED DIALOGUES

N.B. Core Team members attended all days. They are not listed here

University of Aberdeen, February 2016

- Aileen Ackland (Lecturer in Adult education, University of Aberdeen)
- Jan Van Boeckel (Presenter)
- Liz Curtis (Lecturer in Primary education, University of Aberdeen)
- Carolyn Cooke (Research assistant and Doctoral student in Music education, University of Aberdeen)
- Stephen Day (Senior Lecturer in Science education, University of West of Scotland)
- Katrina Foy (Lecturer in Primary education, University of Aberdeen)
- Jen Clarke (Research Fellow in Anthropology, University of Aberdeen)
- Daniel Wodah (Doctoral student in science education, University of Aberdeen)
- Barry Donaldson (Aberdeen City Council, Creativity development officer)
- Fiona Saunders (Aberdeen City Council, Primary science development officer)
- Kirsten Darling-McQuistan (Lecturer in Primary education, University of Aberdeen)
- Donald Gray (Presenter; University of Aberdeen)
- Tim Ingold (Presenter; University of Aberdeen)
- Colin McGill (Education Scotland; Secondary Science development officer)
- Geraldine Mooney Simmie (Presenter; University of Limerick)
- Invited participants who expressed interest but sent apologies on the day: Dr. Joan Parr (Creative Scotland); Dr. Audrey McDougall (Scottish Government); Marie Rennie (Oldmeldrum Academy)

University of Cambridge, Friday April 2016

- Julie Alderton (Lecturer in Mathematics Education)
- Nick Corston (Co-founder of and facilitator for STEAM.Co)
- Stephen Fairbanks (Doctoral student Girton College)
- Kristof Fenyvesi (Presenter, The Bridges Foundation The Experience Workshop MathARt Movement University of Jyväskylä, Department of Art and Culture Studies, Finland)
- Cindy Forde (Presenter, CEO Cambridge Science Centre)
- Ben Gibbs (Director of Restart-Ed Ltd)
- Rick Hall (Founder and Associate of Ignite Futures Ltd)
- Stephanie Hartick (Art Branches. Managing director)
- Lyndsey Hetherington (Lecturer in Science Education, University of Exeter)
Reviewing the potential and challenges of developing STEAM education through creative pedagogies for 21st learning: how can school curricula be broadened towards a more responsive, dynamic, and inclusive form of education?

- Riikka Hoffman (Lecturer in STEM, University of Cambridge)
- Tony Houghton (STEM researcher and facilitator on EU projects, University College Suffolk)
- Ioana Sonia Ilie (Lecturer in STEM University of Cambridge)
- Elsa Lee (School Governor and advocate for STEAM Homerton College)
- Ruth Kershner (Lecturer in Primary ITE and Science Education University of Cambridge)
- Bill Nicholl (Lecturer in Design and Technology University of Cambridge)
- Carrie-Anne Philbin (Presenter, Computer Science educator and Education Champion for Raspberry Pi Foundation)
- Julie Blake (Director of the National Poetry by Heart Foundation and doctoral student, University of Cambridge)
- Tyrone Pitsis (Interdisciplinarity specialist, University of Leeds)
- Fran Riga (Science Education researcher, University of Cambridge)
- Marcus Romer (Arts Beacon Ltd.)
- Charlotte Slade (Lecturer in Education and performance artist, University of Winchester)
- Rae Snape (Presenter, Head teacher, Spinney Primary School and advocate of STEAM. Co)
- Susan Steward (Project Commission Research Assistant)
- Anna Vignoles (Director of Research, University of Cambridge)
- Helen Weinstein (Creative director/ History works)
- Mandy Winters (ITE Secondary Music/Arts Educator and EdD student, Oxford Brookes University)
- Invited participants who sent apologies on the day: Prof. Keith Taber (University of Cambridge) Professor of Science Education

University of Warwick, Thursday 14 July 2016

- Mark Boylan, Reader, Maths education, Institute of Education, Sheffield Hallam University, movement artist. (Table facilitator)
- Sarah Bracken, Children’s Chancellor (Deputy Head teacher), Advanced skills teacher – Art and creativity. Finham Primary School, Coventry
- Rebecca Cain, Associate Professor in Experiential Engineering, WMG University of Warwick (Respondent)
- Ally Caldecote, Ogden Trust School Fellow and Physics Outreach Officer, University of Warwick (Table facilitator)
- Jocelyn Cunningham, Arts and Society, RSA associate (Respondent)
- Amanda Finch, Teacher, Design and Technology coordinator, Our Lady of the Assumption RC Primary School, Coventry
- Lyn Haynes, Senior lecturer, Science education, Director INSPIRE PGCE, Christchurch Canterbury University,
• Jane Hytch CEO, Imagineer Productions (Presenter)
• Lindsay Hetherington, Senior Lecturer in Science Education, University of Exeter (Presenter)
• Lucy Jakubecz, Science teacher, President Kennedy Secondary School, Coventry
• Jo James, KS3 Curriculum lead, Art and Design, President Kennedy Secondary School, Coventry
• Sue Johnstone-Wilder, Associate Professor, Maths phobia, Centre for Education Studies, University of Warwick
• Martin Kechura, Biomedical Science, University of Wolverhampton (Table facilitator)
• Michael Kirby, Teacher, St Thomas More RC primary school, (Maths coordinator)
• Jennifer Kitchen PhD student, Drama Education, University of Warwick
• Wanda Lewis, Engineering, University of Warwick (Engineering through natural design)
• Richard Machin, Head Teacher, Finham Primary School, Coventry (Respondent)
• Kendra McMahon, Science Education, Bath Spa University
• Antonis Michailidis, External relations WMG, University of Warwick (Engineering design, STEM ambassador)
• Ed O’Hara, Deputy head teacher, Maths coordinator, Stivichall Primary School
• Sue Price, Teacher, STEM coordinator, Stivichall Primary School
• Sophie Reisner-Roubichek, Centre for Applied Linguistics, University of Warwick
• Dainar Rusak, MBA student, University of Warwick
• Katia Schubert, MA student, Educational Leadership, University of Warwick (Event set-up; Registration)
• Gaynor Sharp, Co-director Samphire STEM (STEMNET), ASE Field officer, RAEng (Respondent)
• Charlotte Slade, CREAT-IT/CREATIONS project, University of Exeter
• Robert Soderstrand, MA student, Drama and Education, University of Warwick (Event set-up; video recorder)
• Pat Thomson, Professor of Education, Faculty of Social Sciences, University of Nottingham
• Mike Tovey, Reader in design pedagogy, School of Art and Design, Coventry University
• Andrew Townsend, Associate Professor (Science education), Faculty of Social Sciences, University of Nottingham
• Sarah Worth, Co-director, Highly Sprung Performance Company (Physical Theatre, Youth, community and School work) (Table facilitator AM)
• Mark Worth, Co-director, Highly Sprung Performance Company (Physical Theatre, Youth, community and School work)
APPENDIX F: DISSEMINATION EVENTS

This is a date-sequenced list of talks and conference presentations on STEAM education and related debates delivered by members of the core team over the course of the review – the most recent first. Underlined entries received support from BERA. Non-underlined entries benefitted from support of external sources. Where multiple authors are listed, presenters are emboldened.


session at the Launch of the Curriculum Network, University of Stirling, 9th November 2016, Stirling.

12. Trowsdale, J. (2016) ‘Developing STEAM education? Using a specific arts and engineering project to consider the significance of creativity as a site for re-appraising the curriculum’, Presentation as part of BERA Creativities in Education Special Interest Group day conference: Advancing Creativity Research: Making Connections across Diverse Settings, University of Cambridge, 28th October 2016, Cambridge.


17. Colucci-Gray, L. (2016). The ethical dimension in the dialogue between the nature of science and global citizenship education. Invited panel member and round-table participant at the Roundtable Research on the teaching of the nature of science, with Fouad Abd-El-Khalick (University of Illinois, USA), Pedro Reis (University of Lisbon) Angel Vazquez (UIB Espana). III International Symposium of Science Education (SIEC 2016), an online congress on research in science education, organised by Dr. Pedro Reis (University of Lisbon), 16th June 2016.

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