An Roinn Oideachais
Department of Education

Review of Literature to Identify a Set of Effective Interventions for Addressing STEM and the Arts in Early Years, Primary and Post Primary Education Settings

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Developed by the STEM Education Team
at Mary Immaculate College, Limerick.

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Context

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Executive Summary

Background

The last decade has been marked by a growing momentum to advance STEAM (Science, Technology, Engineering, Arts, and Mathematics) education nationally and internationally. This fast-evolving field is characterised by its efforts to incorporate the arts into STEM (Science, Technology, Engineering, and Mathematics) education. Where 'integration' is mentioned in this report, it refers to the integration of any of the arts disciplines with any of the STEM disciplines. Despite the popularity of STEAM education and the proliferation of STEAM-related initiatives, there is considerable divergence in conceptualisations, understandings, and/or a shared purpose of STEAM, in educational endeavours. There is an evidence-based disparity in relation to the crucial components that contribute to high-quality STEAM education experiences. The variety of manifestations of STEAM reflect the tensions and aspirations arising from the perspectives of the disciplines and practitioners that contribute to it. Consequently, STEAM education can be considered an embryonic field that is currently weakly theorised.

Advocates for STEAM education acknowledge the transformative learning potential of STEAM education and proffer compelling arguments in support of institutionalising the role of the arts in relation to science, technology, engineering, and mathematics learning. Some identify the pervasive need for improving STEM education and making it accessible to all students, especially those in historically marginalised communities. From this perspective, the arts provide a compelling context and entry point to engage underrepresented groups in STEM. This is because of emerging evidence that arts-based approaches offer scope to exploit culturally relevant pedagogies and to attribute value to a range of cultural capitals. Many that hold this viewpoint also recognise the significant value that the arts offer, including its potential benefits in developing 21st century skills, enhancing innovation and creativity in STEM, contributing to economic prosperity, feeding the STEM pipeline, and increasing global competitiveness. One consequence of this perspective is that the arts are positioned as providing value to STEM education without displacing the focus on the traditional STEM disciplines. This leads to positioning STEM as more important and locating the role of the arts as integrating *into* STEM in the service of elevating STEM learning.

In contrast, other STEAM advocates see the arts and STEM as co-equal and eschew valorising one over the other. Within this perspective, STEAM education is considered a transdisciplinary endeavour focusing on a hybrid creative and critical inquiry between the arts and STEM that involves innovative, problem and project-based, high-quality learning experiences delivered in a collaborative and integrative manner. This view of STEAM education utilises arts integration as an instructional approach, providing multiple entry points for students to engage in the creative process, thus meeting the learning objectives of arts and STEM subjects. Within these spaces, all disciplines have equal value and are engaged coequally; the arts and STEM are seen to make mutually beneficial contributions to teaching and learning.

Ireland is among a number of countries worldwide that have a STEM Education Policy Statement, but have no comparable national policy for STEAM education. However, Ireland's STEM Education Policy Statement 2017-2026 recognises the synergy between STEM and arts education and acknowledges the benefits arising from the integration of STEM and the arts. The purpose of this systematic review of the literature is to review national and international STEAM literature and identify a set of effective interventions for addressing STEAM in formal (early years, primary, post-primary) and informal education settings. In this report, 'informal' education settings refer to structured, intentional programmes in out-of-school settings, such as clubs and camps. These education settings are generally labelled 'non-formal'. It is important to note that where barriers to effective STEAM education are highlighted in the synthesis of results, these barriers reflect a synopsis of those challenges identified and consequently extracted from the selected literature. The actions and recommendations arising from the review will contribute to developing STEAM education policy in Ireland.

Terms of Reference

This systematic review synthesises research reporting on the effectiveness of STEAM interventions in formal and informal settings and reports on the characteristics of these interventions. The objectives of this report are outlined in the following Terms of Reference (ToR):

ToR1: Identify the relevant, evidence-based/rigorously argued propositions that promote arts education in parallel with STEM education and the inclusion of arts as an integral part of STEAM learning.

ToR2: Analyse international sector-wide policies or practices that exist to promote STEAM learning.

ToR3: Evaluate how learning in the domains of STEM and the arts are mutually beneficial within formal and informal settings, and identify any limitations therein:

a) What are the key barriers and challenges (including, for example, policy frameworks, cultural factors, and resources) to successful learning outcomes in STEAM education?

b) What are the key enablers and opportunities (with evidence of effectiveness) that support high quality learning in STEAM education and support the development of learners' and educators' critical dispositions, skills, knowledge, beliefs and values in relation to effective STEAM learning?

ToR4: Synthesise the risks and challenges in promoting STEAM education policies and practices in terms of possible unintended consequences or collateral impact.

Methodology

The review was conducted in three phases. Phase 1 was concerned with protocol development, an electronic search of education databases and a manual search of targeted journals. It incorporated a bibliographic search that indexed a range of academic journals: Scopus, Web of Science, ERIC (ProQuest), and EBSCO. This database search also incorporated published conference proceedings to identify emerging STEAM education research that had not yet been published in academic peer-reviewed scholarly journals. To reduce the risk of publication bias, sources including unpublished or 'grey' literature were searched. Following the removal of duplicates, this phase yielded 2484 files.

Phase 2 focused on the formulation of five study exclusion criteria, a pilot study to test the efficacy of the criteria, study selection, and consistency checks of the screening process. Input from an advisory board of visual and performing artists, art educators, and an expert in STEM education, measurement and research design informed the development of exclusion criteria. The five exclusion criteria were applied, and 179 studies were extracted.

Phase 3 involved the analysis and synthesis of extracted studies where an array of relevant research studies was identified and described, including research involving STEAM education interventions across formal (early years, primary, post-primary) and informal (structured, intentional, out-of-school) settings in addition to consideration of the landscape of initial teacher education.

Main Findings

The design of studies conducted in STEAM education reflects this nascent area of research. There were few highly rigorous empirical studies of STEAM education interventions that featured randomisation, control groups and robust statistical analysis. This is understandable given that STEAM education is new, and there is still a level of ambiguity among practitioners and researchers as to what effective STEAM education entails. The selected studies described in this report showcase extant research featuring the most robust empirical design, reflect the dominance of mixed-method studies, and report qualitative studies that provide insights into the characteristics of high-quality STEAM interventions and focus on learners' experiences using student voice and rich description.

Across all sectors, most interventions focused on one STEM discipline (science, technology, engineering, or mathematics) combined with one arts-based domain (from the visual, performing, or musical arts). There were consistent patterns in the integration and pairing of disciplines. Most studies integrate science with the visual arts at the early years and primary level. In contrast, science was integrated with the dramatic arts at post-primary level, and few studies integrated visual arts with any of the STEM disciplines. At post-primary level, mathematics was most frequently combined with music. However, at the early years and primary level, mathematics was paired equally with the visual and performing arts. Technology was integrated most often with the musical arts or dance at post-primary level and drama at the early years and primary level. Compared to the formal school sector, STEAM education interventions in the informal sector integrated the arts with more than one STEM discipline. These patterns are plausible given the generalist context of early years and primary level, the subject specific nature and teacher specialists found at post-primary, and the diverse educational landscape that is found in a myriad of informal settings. The review of intervention studies at post-primary highlights the need to broaden the domains of integration within STEM and across the arts. That said, studies that tried to do too much, too soon, such as those that attempted to implement a whole school approach to STEAM, were counterproductive in some cases. Within the informal STEAM education landscape, there was a notable imbalance between the arts and STEM subjects evident within interventions, where STEM subjects like mathematics received little explicit attention. Similarly, at the early years and primary level, relatively few studies explored the potential for music integration. This may point to issues of researcher access, research focus or inherent requirements of funding agencies; however, confirmation of a rationale for this observation is beyond the scope of this report.

The enablers for effective STEAM education within formal education settings were consistent across the studies, with the importance of teacher professional development, the cooperation of an interdisciplinary team, connections with stakeholders inside and outside the school, adaptability of the formal curricular structures to facilitate projects, a constructivist approach to teaching and learning and the critical role played by meaningful and equal integration of the arts-based elements of the intervention. Additionally, play-based approaches were identified as effective for successful STEAM integration in primary education settings, as was embracing young children's natural curiosity. For informal settings, enablers included access to relevant professional development courses, technologies and expertise, promotion of student-led learning, thus promoting agency, creativity, and the opportunity to develop both arts and STEM understandings.

Barriers to effective STEAM education implementation commonly cited within both formal and informal education settings included an over-focus on the STEM discipline at the expense of the arts, low levels of self-efficacy and expertise of educators implementing STEAM education initiatives, lack of time and scarcity of resources for projects within pressured formal curricula, alongside the absence of a unified and mutual understanding of STEAM education. There was also a lack of leadership and practitioner support for STEAM education in the formal education setting.

Many of the studies included a research question that addressed a cultural concern or question around representation and inclusivity within STEM education. This is important as gender, race and social class can intersect to create a persistent hegemonic STEM landscape in schools and society. Few studies focused solely on a critical perspective and usually included a substantial research component to measure knowledge development, attitude, or interest in STEM or STEAM education. A mutual and equal valuing of both arts and STEM was evident in many studies; however, in both the formal and informal sectors, there was a significant proportion of studies where integration of the arts was superficial or merely to promote communication of STEM knowledge. This was evidenced in a smaller proportion of studies focusing on developing knowledge and dispositions in the arts, rather than an exclusive focus on STEM disciplines. The research agenda of funding agencies may have also influenced the emphasis of inquiry and research questions.

Conclusions

This review highlights that STEAM education is at an exploratory and early phase. There is significant scope for innovation and creativity regarding research focus, design, and implementation of STEAM education interventions. The defining feature of STEAM education is the integration of the arts. Consequently, explicit attention must be given to learning outcomes for the arts arising from any STEAM education intervention. This is best achieved through collaboration between the arts and STEM education communities in the design of high-quality STEAM curricula, the development of assessment strategies, and evaluation of outcomes. This can be guided by STEAM policy that promotes a shared understanding of what STEAM education entails and articulates a unified purpose for STEAM education. Such policy must provide a rationale for its use and not privilege one over the other, either the arts or STEM. Furthermore, any policy initiative needs to be cognisant of the *learner* in terms of who they are, how they access STEAM education opportunities, and the most appropriate pedagogies to support their learning. Investment must also be made into supporting the *educators* through the provision of high-quality initial teacher education and professional development that targets the development of knowledge, skills, and dispositions to support STEAM learning in classrooms and informal settings.

Section 1: STEAM Education – Global Perspectives on Policy and Practice

A rationale for integrating the arts with STEM education

The last decade has been marked by a growing momentum to advance STEAM education nationally and internationally. This fast-evolving field is characterised by its efforts to incorporate the arts into STEM (Science, Technology, Engineering, and Mathematics) education. Despite the popularity of STEAM education and the proliferation of STEAM-related initiatives, there is considerable divergence in conceptualisations, understandings and a shared purpose of STEAM, in educational endeavours. There is an evidence-based disparity in relation to the crucial components that contribute to high-quality STEAM education experiences. The variety of manifestations of STEAM reflect the tensions and aspirations arising from the perspectives of the disciplines and practitioners that contribute to it. Consequently, STEAM education can be considered an embryonic field that is currently weakly theorised.

Advocates for STEAM education acknowledge the transformative learning potential of STEAM education and proffer compelling arguments in support of institutionalising the role of the arts in relation to science, technology, engineering, and mathematics learning. Some identify the pervasive need for improving STEM education and making it accessible to all students, especially those in historically marginalised communities. From this perspective, the arts provide a compelling context and entry point to engage underrepresented groups in STEM. This is because of emerging evidence that arts-based approaches offer scope to exploit culturally relevant pedagogies and to attribute value to a range of cultural capitals. Many that hold this viewpoint also recognise the additional value that the arts offer, including its potential benefits in developing 21st century skills, enhancing innovation and creativity in STEM, contributing to economic prosperity, feeding the STEM pipeline, and increasing global competitiveness. While the 21st century skills (in particular the four C’s - communication, collaboration, critical thinking and creativity) have been advocated as important, *creativity* has been highlighted as a key skill for future generations in Korea (Kim & Kim, 2017). In the United States, the case to advocate for the inclusion of *creativity* with STEM was developed in the context of the 2008 economic crisis to ensure US economic competitiveness (Allina, 2018). Furthermore, promoting creativity and recognising student learning diversity could increase student engagement and potentially enhance

STEM learning by embracing cross-cutting translational skills common to STEM, and arts and design disciplines (Allina, 2018). One consequence of this perspective is that the arts are positioned as providing value to STEM education without displacing the focus on the traditional STEM disciplines. This leads to positioning STEM as more important and locating the role of the arts as integrating *into* STEM *in the service of* elevating STEM learning.

In contrast, other STEAM advocates see the arts and STEM as co-equal and eschew valorising one over the other. Dell'Ebra (2019a) outlines how STEAM education is more than arts integration. STEAM education provides opportunity for analytical thinking (most often associated with STEM subjects) and creative expression (most often associated with the arts) to combine and foster innovation (Dell'Ebra, 2019a). Within this perspective of co-equality, STEAM education is considered a transdisciplinary endeavour focusing on hybrid creative and critical inquiry between the arts and science that involves innovative, problem and project-based, high-quality learning experiences delivered in a collaborative and integrative manner. Within these spaces, all disciplines have equal value and are engaged coequally; the arts and STEM are seen to make mutually beneficial contributions to teaching and learning.

Position of STEAM in international education policy

It is important that policy for STEAM education reflects three key elements of the education system: *the teacher who teaches, the student who learns, and the educational content that mediates the teaching and learning* (Shin, 2005). Like Ireland (DES, 2017), many countries have completed their own policy review and outline an implementation plan for STEM education but have no comparable national policy review of STEAM education.

The most recent key stage 1 to 4 (primary to lower secondary) school curricula in the UK (Department for Education, UK, 2014) and Wales (Welsh Government, 2008) have no explicit mention of STEM/STEAM integration. The subject disciplines remain distinct at curriculum level. In comparison, the Scottish Government have started their implementation of a STEM education and training strategy (Scottish Government, 2020). The Scottish government published their third annual report on STEM Education in March 2021. However, there is no mention of STEAM or Arts integration in this STEM report. In Sweden, mathematics, arts, technology and individual science disciplines are presented as separate learning areas in the national compulsory school curriculum (The Swedish National Agency for Education- Skolverket, 2018).

The Australian school curriculum (Australian Curriculum, 2021) identifies cross curricular areas for learning to be addressed through learning areas and do not constitute curriculum on their own. They include Aboriginal and Torres Strait Islander histories and cultures, Asia & Australia’s engagement with Asia, and Sustainability. Science, mathematics, art and technologies remain distinct learning areas on the curriculum.

The promotion of STEAM education is beginning to be recognised and included as part of educational reform in some countries. For example, Romania have included the promotion of STEAM as one of 10 priority areas in their national curriculum: “*Promoting STEAM (science, technology, engineering, arts and mathematics) education: encouraging the participation of school students in STEAM activities, preparing teachers to teach STEAM contents, ensuring the necessary endowment for teaching STEAM subjects, relevant external partnerships”* (Eurydice, 2021). The National Plan for Digital Schools in Italy (Eurydice 2016) mentions STEAM in an effort to strengthen the link between school and work, through entrepreneurship education and the promotion of STEAM and digital careers (Eurydice, 2016).

Exploratory work in school clusters in New Zealand has evidenced some effective STEAM practices and learning. The STEAM practices are student-centred, hands-on with a focus on transfer of knowledge from different learning areas. “*In STEAM inquiries, teachers and students can make use of the natural connections between learning areas. Teachers involved [in the WAPA 2020 cluster] support their students to transfer knowledge and skills from a range of learning areas to their STEAM projects. Learning is also linked to the NZC values and key competencies”* (New Zealand Ministry of Education, 2020).

Comparing two international approaches to STEAM education

Consistent with previous reviews in STEM education (e.g. Li et al., 2020) where most research publications were contributed by authors from the US, Australia, Canada and Taiwan where STEM and STEAM education originated, Korea and the US provide comparable examples of developed STEAM policies.

KOREA

The *Korea Foundation for the Advancement of Science and Creativity (KOFAC)* has managed the systematic STEAM education programmes at the national level since 2011. The following key concepts were considered when designing STEAM education in Korea: Creativity, Ability to create value and Personal capability (Choi & Hwang, 2017). To help STEAM education become better established, KOFAC supports teacher education, distribution of content, exploratory student activities and institutionalises STEAM education (Hong, 2017). Choi & Hwang (2017) describe STEAM education as a new paradigm for science education to foster strategic and global talents, in particular convergence-thinking abilities. The concepts framing STEAM education (Choi & Hwang, 2017) in Korea include:

- Systematic interdisciplinary links between science, technology and engineering, with an aim to nurture convergent creativity;
- Convergent thinking is presented as creative thinking about how to connect STEM fields;
- Outlining a roadmap to cultivate creative science talent through diversity of applications for scientific knowledge in STEAM fields;
- Connections and convergence of science, technology, engineering and mathematics with social systems;
- Cultivating human resources to contribute to global developments in science, technology and engineering;
- Nurturing science, technology and engineering education to include moral and ethical awareness;
- Using creative hands-on teaching methodologies.

A learning standards framework of STEAM classes has been established in Korea at a class and school level. This framework has three levels: *context presentation, creative design and emotional touch,* for use in all STEAM lessons (Korea Foundation for the Advancement of Science and Creativity, 2016). Almost one third (27.1%) of all schools (elementary, middle and high) implement STEAM education, and this implementation is attributed to the voluntary efforts of individual teachers (Hong, 2017). A three step STEAM professional development programme is currently being operated. The steps are *introductory training* (helping teachers understand the concepts and policies of STEAM), *basic training* (15-hour online programme to implement STEAM in schools) and *intensive training* (blended learning to improve teachers' capabilities to develop and implement STEAM) (Hong, 2017). Based on their research, Jho, Hong, and Song (2016) recommend that STEAM professional development programmes should focus on developing a learning community that is activity orientated (as distinct from individual and content learning) to best support sustainable professional development.

Analysis of students' learning of STEAM in Korea has found that students who participated in STEAM classes showed higher preference for science as well as higher levels of self-directed learning (Hong, 2017). Students cited group work activities and connecting learning in various subjects as important and enjoyable aspects of STEAM learning (Kang et al., 2017). A review of STEAM education materials developed in Korea found that most STEAM education at elementary level integrated science and visual art, while more second level STEAM education integrated technology and engineering (Ahn & Kwon, 2017). STEAM outreach programmes and STEAM Research & Education (R&E) festivals have had a positive impact on students' cognitive, affective and societal learning (Mun, Mun, Hwang & Kim, 2017).

UNITED STATES (US)

STEAM as an acronym first appeared in 2009 in an Arts Education statement in Florida. In 2010, the National Science Foundation (NSF) and National Education Association (NEA) established a joint committee to identify synergies, with one outcome initiating a recommendation for investment in STEAM education research. Subsequently, the network for Science, Engineering, Arts and Design (SEAD) focused on art and science integration from 2012-2015. The Arts Education Partnership (AEP) and National Association for Music Education were among those supporting the STEAM education movement. STEAM education has been described as creative, experiential, inquiry based and interdisciplinary in the US. Six core STEAM education practices (Dell'Ebra, 2019b) include:

1. Leveraging concepts in one or more STEM disciplines to create meaningful artwork;
2. Focusing on outcomes that have a personal and/or aesthetic meaning;
3. Conducting open exploration in the context of both science and art;
4. Designing with intention;
5. Iterating through several drafts, prototypes or models;
6. Communicating about the process and outcome.

It is important that the arts (and design) are recognised as core subjects alongside STEM and Allina (2018) has called for research into potential outcomes of STEAM education models and funding for professional development and latitude for teachers to explore interdisciplinary learning in the US. Furthermore, Alina (2018) argues that the provision of resources and the issue of equity in arts education need to be addressed.

Allina (2018, p.83-84) has outlined best practices of high-quality STEAM education, which provide insight into how to implement meaningful STEAM education:

- Incorporates the expertise of both STEM and arts educators to create a natural interdisciplinary experience for students: co-teaching model/co-planning is strong and replicable;
- Is thoroughly planned, including the identification of state or national standards in each subject area, balancing standards offered from each subject equally;
- Borrows from scientific method, the iterative artistic and creative processes, and artistic production and exhibition as critical milestones in the experience;
- Has the buy-in of school administrators;
- Leverages local artists, artisans, scientists, area non-profits and other experts, as appropriate;
- Is well documented through photography, lesson plans, and other means, as a method of advocacy and to ensure partnership longevity for STEAM as a new instructional method;
- Has a tangible outcome, such as an artistic product, scientific experiment, architectural or design specs, or other artefacts;
- Allows students to direct their own learning through experimentation, positioning teachers as guides and personalising learning;
- Leverages real-world connections wherever possible and highlights the nexus of career and technical education and the arts;
- Includes built-in, tailored assessments that help students and teachers understand what students have learned and what they have not;
- Includes solid, clear, and well-constructed rubrics that integrate the arts.

Analysis of the Korean policy development provides implications that it is driven from a science, technology and engineering perspective (with limited explicit mention of mathematics, and less mention of Art). In comparison the development of STEAM policy in the US is more informed from an Arts perspective. "*Including the arts in STEM learning can further enhance teaching and student achievement, and build upon existing approaches to STEM that encourage students to apply creativity to solving real-world problems"* (Dell'Ebra, 2019b). The Korean STEAM policy places a strong focus on *convergent thinking*. In comparison, *divergent thinking* is presented as one of four types of learning in the US STEAM policy: active learning, social and emotional learning, divergent thinking and cultural competency. The US's Education Commission of the States Policy brief (2019) described STEAM education as the use of arts integrations as an instructional approach for experiential and inquiry-based learning, providing multiple access points to engage students in the creative process and meet objectives in all subject areas. Some barriers and gaps in STEAM education and policy include a lack of a shared definition for STEAM education, lack of effective teacher preparation and professional development, curricular restraints, capacity (e.g. resources, scheduling) restraints and a lack of rigorous research on STEAM education (Dell'Ebra, 2019a).

Many questions exist as STEAM education evolves, such as what unique value do the arts bring to STEM and STEM to the arts? What is the workforce rationale for STEAM skills? What are the policy opportunities to support arts learning in STEM? There is also opportunity to investigate whether STEAM could be a model that will help attract women and minorities into STEM fields. STEAM education and policy development merit future research and development.

Section 2: Methodology

The overarching aim of the systematic literature review was to identify a set of effective interventions for addressing STEAM in early years, primary and post-primary education settings. A six-phase Systematic Literature Review (SLR) protocol was used to structure the review (Fink, 2019; Boland, Cherry & Dickson, 2017; Hart, 2017; Gough, Oliver & Thomas, 2017; Heyvaert, Hannes & Onghena, 2016):

1. Formulation of research questions/objectives of the review
2. Selection of sources
3. Determination of search terms within these sources
4. Application of practical and methodological criteria for the selection of high-quality scientific literature
5. Conducting the review i.e., importing bibliographic data and eventually full texts; defining variables such as author, year of publication, etc.; thematic coding of significant text segments, writing notes and summaries.
6. Synthesis of results and writing up the review, in the form of a qualitative description of results.

Formulation of Terms of Reference for the review

To fully address these main objectives, four terms of reference (ToR) were developed:

ToR1: Identify the relevant, evidence-based/rigorously argued propositions that promote arts education in parallel with STEM education and the inclusion of arts as an integral part of STEAM learning.

ToR2: Analyse international sector-wide policies or practices exist to promote STEAM learning.

ToR3: Evaluate how learning in the domains of STEM and the arts are mutually beneficial within formal and informal (structured, intentional, out-of-school) settings, and identify any limitations therein:

a) What are the key barriers and challenges (including, for example, policy frameworks, cultural factors, and resources) to successful learning outcomes in STEAM education?

b) What are the key enablers and opportunities (with evidence of effectiveness) that support high quality learning in STEAM education and support the development of learners' and educators' critical dispositions, skills, knowledge, beliefs and values in relation to effective STEAM learning?

ToR4: Synthesise the risks and challenges in promoting STEAM education policies and practices in terms of possible unintended consequences or collateral impact.

Selection of sources

Given that both STEM Education (Li et al., 2020) and STEAM education (Mejias et al., 2021) are both somewhat ill-defined fields, conducting a comprehensive literature review of STEAM education research requires careful thought and clearly specified scope to tackle the complexity naturally associated with STEAM education. To identify a representative sample of the research literature, targeted systematic literature reviews incorporate searches of electronic databases, examination of grey literature (such as government reports, policy statements and issue papers, theses and dissertations, and research reports), and hand searches of journals. All three types of searches were employed using specific pre-agreed search terms representing the topics in question. Across all three search types, searches were limited to studies that reported empirical findings to focus on STEAM approaches that had been implemented and evaluated within educational settings.

In the first search strategy, examining electronic databases, the focus was placed on peer-reviewed journals as these sources report empirical studies generally of high quality. Bibliographic databases were incorporated into the search to locate these studies because they indexed a range of academic journals. Different bibliographic databases index various journals; consequently, Scopus, Web of Science, ERIC (ProQuest), and EBSCO were searched as they include journals and conferences relevant to STEAM education contexts. As STEAM is a multidisciplinary field, to ensure coverage beyond education journals, the search was concluded with a search of Summon, which searches across the entire Online library collection and covers any additional journals not included within the former four databases.

The second search strategy was used to reduce the risk of publication bias (Chapman et al., 2014) in the search findings. Publication bias, where studies that do not report positive outcomes or effects are less likely to be published and, in turn, more difficult to find, is always a concern when reviews examine the effectiveness of educational interventions. The reduced likelihood of including such studies that report a negative or small effect in a review can lead to overestimating the positive impact of an educational intervention (Chow & Eckholm, 2018). Consequently, the second search strategy focused on sources, such as ProQuest Dissertations and theses, which include these unpublished or 'grey' literature. The electronic database search also included published conference proceedings in an effort to identify emerging research that had not been published in academic peer-reviewed scholarly journals.

The third search strategy focused on identifying disciplinary-specific articles that may have been missed in the initial database searches. A manual search of relevant journals was carried out across a pre-defined set of discipline-specific journals (arts, mathematics, science, STEM, engineering and technology) to supplement the electronic database searches. Based on a systematic review of journal publications, research, and trends in STEM education (Li et al., 2020), we started with the top five journals in terms of the number of STEM education publications: Journal of Science Education and Technology, Journal of STEM Education, International Journal of STEM Education, International Journal of Engineering Education, and School Science and Mathematics. We also incorporated journals that focused on STEAM education, arts education and journals that facilitated capturing STEAM education research in informal and other (i.e., library) settings (see appendix A).

Determination of search terms within these sources

We used the PIO (Population, Intervention, Outcome) framework to facilitate the determination of the search terms. This framework is a modification of the commonly used PICO (Patient/problem/population, Intervention, Comparison/control, Outcome) framework used in medical studies (Sharma et al., 2015). The framework's C component (referring to a comparison intervention group) is often considered unsuitable for educational reviews. This is due to the inequality in educational outcomes associated with not delivering an intervention to a group. In addition, STEAM education is in its infancy and there are very few large-scale randomised control trials with assigned control/comparison groups. Consequently, we chose to focus on the PIO components and not incorporate attention to the C component when determining search terms and criteria.

Our search strategy incorporated eligibility criteria for the *population* in the study. The population of interest is people experiencing STEAM education interventions and were identified as students, educators, or curriculum designers. The educational settings within which the population is found range from provision in early childhood, primary through to post-primary level in formal and informal settings. Eligibility criteria were developed for defining *interventions*. The intervention is implementations of STEAM education that may be delivered in formal (school/college) or informal (clubs, camps) settings across the education continuum, ranging from early childhood settings to post-primary settings. Selecting review *outcomes* was of interest to us in the systematic literature review. Outcomes of interest were identified as attitudes, skills and behaviour arising from engagement with STEAM education. However, as McKenzie, Brennan, Ryan, Thomson, Johnston & Thomas (2019) recommended, outcomes were not used as part of the criteria for including studies; they became the later focus of attention in the synthesis phase of the study.

This PIO framework was used to guide the selection of search terms. A large number of trial searches and scoping exercises were carried out initially to ensure the databases indexed an appropriate range of relevant journals and that the selected search terms captured a suitable range of studies. An initial list of keywords was formulated under an adapted version of the PIO Framework for vocabulary selection. These keywords were used to run some initial searches. The metadata from the results were then used to expand the list into a broader range of terminology incorporating synonyms, various word forms, plural forms and geographic location. The metadata included keywords, subject headings and author-supplied words from the literature. Appendix B presents an initial list of keywords formulated under the PIO framework and sample searches using the relevant search syntax.

Arising from these initial searches, a series of search queries were developed. For each of the four databases (Scopus, Web of Science, ERIC-ProQuest, and EBSCO), 28 searches were carried out across five populations: early years, primary, secondary, informal, and STEAM. Appendix C describes the search queries used within each of the five populations. Results from the electronic database searches, grey literature searches and hand searches were combined, yielding 5030 files. All hand searches were found to be duplicated within the database searches. A search for duplicate titles was conducted and 2546 files were removed.

Category	**EBSCO**	**Web of Science**	**Scopus**	**ProQuest**	**Combined Totals**	**Combined Totals after Duplicates Removed**
Early years	185	109	79	197	570	296
Primary	402	289	222	347	1260	597
Secondary	401	612	236	397	1646	750
Informal	59	53	35	28	175	112
STEAM	459	408	102	410	1379	729
	1506	**1471**	**674**	**1379**	**5030**	**2484**

Table 1 - Database Totals

Practical and methodological criteria for selection of scientific literature

The metadata were presented on a spreadsheet. The studies were scrutinised, and studies eliminated due to additional duplicates being found (n=201), studies published prior to 2010 (n=210) and blank lines found on the excel sheet (n=9). This left 2064 studies.

The next step was to define the exclusion criteria. These criteria were the basis upon which the decision was made to include or exclude individual studies. The exclusion criteria (EC) were:

- EC1: The study is not written in English
- EC2: The study does not include school level students or educators (early childhood, primary, secondary or initial teacher education)
- EC3: The study does not represent an integrated approach to the arts and STEM education
- EC4: There is no access to a full text version of the study
- EC5: The included study does not report empirical data pertaining to learning or attitudinal outcomes (dispositions, skills, knowledge, beliefs or values)

Piloting the criteria

Four researchers engaged in a preliminary pilot of the criteria on a sample of 172 studies that emerged from an initial search of the STEAM education literature carried out in Scopus. This pilot was carried out to ensure that sufficient expertise was developed within the team when determining whether studies met the eligibility criteria thus decreasing the likelihood that relevant studies were discarded (Edwards et al., 2002). Researchers discussed the exclusion criteria, independently screened the same 37 studies, met to examine results and then refined the exclusion criteria based on discussions. Researchers subsequently worked in pairs, with each member of the pairing alternating roles as primary and secondary readers, to review the remaining 135 studies. Detailed notes were made around the decision making for each exclusion criteria as it applied to the 172 studies. Arising from examination of the decisions made regarding exclusion, two challenges arose within the group: How do we define the arts within the context of STEAM education? How do we measure 'effectiveness' in empirical research? To address these questions, meetings of the advisory panel were arranged and advice of the experts in the arts, STEM education and empirical research sought.

EC3: Feedback from the advisory team, and the pertinent literature, encouraged an emphasis on studies that meaningfully integrated the arts and STEM. 'Integration' in this report refers to the equal incorporation of any (or more) of the arts with one (or more) of the STEM disciplines. Our emphasis was on authentic integration, wherein the arts and STEM are mutually instrumental, and "neither STEM nor arts are privileged over each other, but both are equally in play" (Mejias et al., 2019, p. 209-210). While acknowledging the important role that the arts can play in broadening participation in STEM learning and advancing economic competitiveness and concomitantly that STEM can play in secure funding for the arts; many studies inspired primarily by such motivations result in shallow representations of STEAM education that fail to harness and mutually promote deep learning in the arts and STEM. This perspective was operationalised in the study by examining the extent to which studies sought explicit learning outcomes in both the arts and STEM arising from participation in the STEAM education initiative.

EC5: Conversations with the advisory team lead to adoption of a framework to guide the identification of research studies that provided evidence of effectiveness. The researchers drew on the cross-agency guidelines of the National Science Foundation (NSF) for improving the quality, coherence, and pace of knowledge development in STEM education. The guidelines resulted from collaborations between representatives from the National Science Foundation (NSF) and the U.S. Department of Education (DE) to “identify the spectrum of study types that contribute to development and testing of interventions and strategies, and to specify expectations for the contributions of each type of study” (NSF, 2013, p.8). This framework consists of six stages of research forming a ‘pipeline of evidence’ (p.8) beginning with basic and exploratory research and culminating in studies that provide evidence of effectiveness of the study intervention. For the operationalisation of this exclusion criterion, the study was required to report some form of data that fell into one of the six NSF categories of research: foundational research, early-stage or exploratory research, design and development research, efficacy research, effectiveness research, and scale-up research.

Study Screening

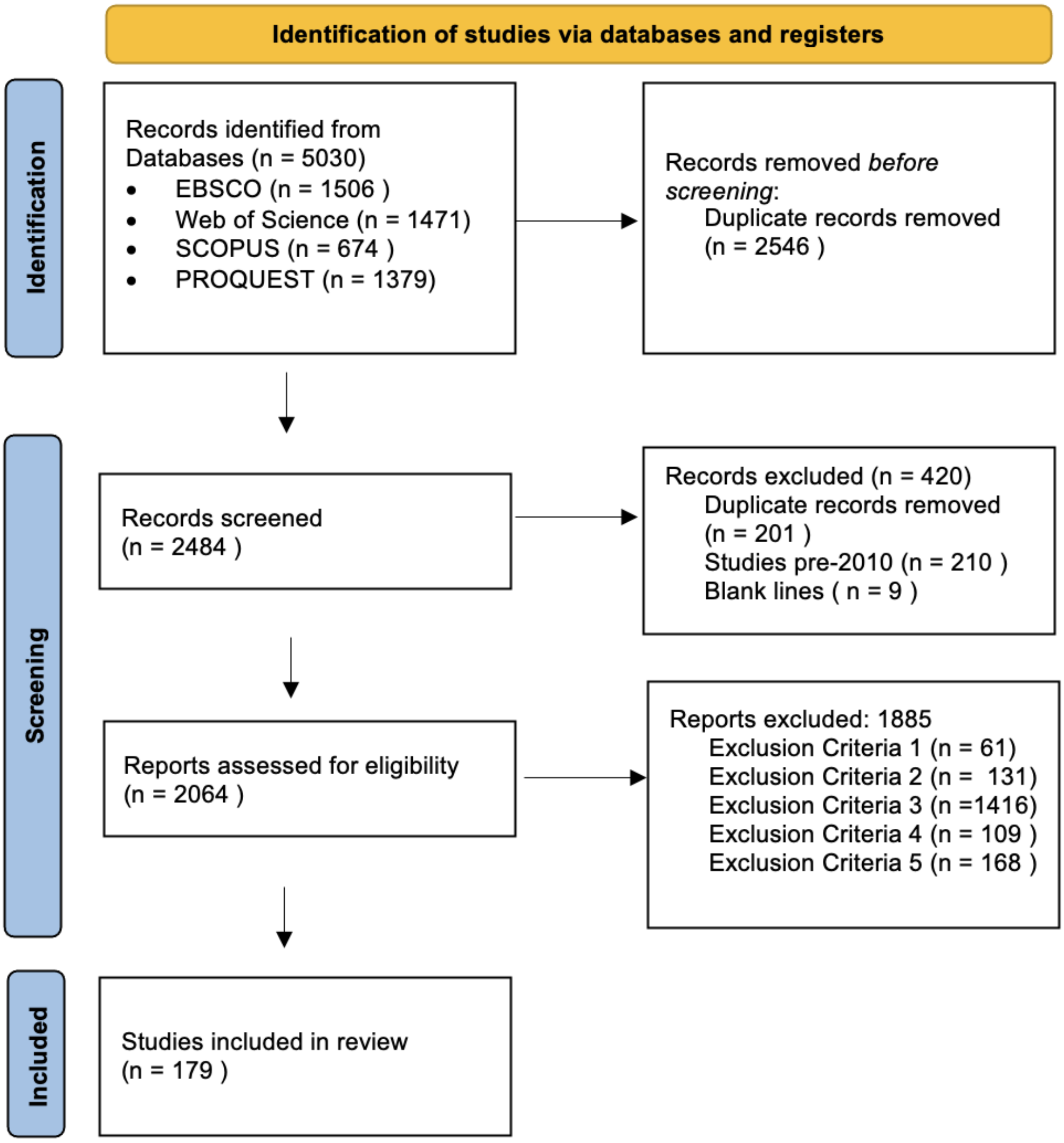

Figure 1: Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) flow diagram

Considerable expertise in operationalising the exclusion criteria was developed from the pilot study. Arising from these learnings, particularly acknowledgement of the workload involved in applying EC5, it was decided to screen the studies in two iterations. The first iteration focused on exclusion criteria one, two, three and four. The second iteration targeted exclusion criterion five.

In iteration 1, four researchers working collaboratively to complete a manual check of study titles and abstracts to determine inclusion or exclusion. Each researcher was assigned the role of first or second reader for a proportion of the 2064 studies (see Appendix D). For each assigned study, the first reader examined whether the study title and abstract adhered to the four exclusion criteria by recording a decision of:

- YES (the study met the criteria),
- NO (the study did not meet the criteria), or
- MAYBE (unable to determine the study relevance based on title and abstract) and assigned an amber colour.

The second researcher checked these same studies and recorded a decision of AGREE or DISAGREE with the decision made by the first reader. For studies assigned the MAYBE status (amber colour), the full text of the study was examined by both readers in order to meet a decision of YES or NO.

Across this phase, a small number of studies warranted further discussion. Meetings of all four researchers were carried out to discuss these studies where there was disagreement or uncertainty. At this meeting, the full text of the papers was examined, and a decision was reached regarding any inconsistencies or conflicts in reviewer decision-making. Applying these exclusion criteria yielded 347 articles at the end of iteration 1.

The studies emerging from iteration 1 were screened once again, this time attending to EC5 (reporting empirical data). For the most part, these studies required a full text screening in order to ascertain the nature of the data (if any) that were collected and used to determine study efficacy. A total of 168 of the remaining studies were eliminated as they provided either, theoretical and philosophical perspectives on STEAM education (n=41) **or** provided descriptive accounts of participants' experience of the STEAM activity that were not grounded within data collection **or** provided no insights into study effectiveness (n=127). Applying this final criterion resulted in 179 studies. Figure 1 presents the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) flow diagram adapted from Page et al. (2021).

Conducting the review

The study screening, utilising the five exclusion criteria, yielded 179 articles that provided potentially relevant studies to assist with addressing the research questions. In order to effectively manage these studies and to maximise the value of certain sector specific research, a categorisation exercise was conducted, which classified these 179 articles by formal or informal educational sector. The following table illustrates the results of this categorisation.

Early Years and Primary	**Post-primary**	**Informal Settings**	**Teacher Education**
60	44	40	35

Table 2- Categorisation of Research Studies by Education Sector

The early years and primary sector were merged at this point due to a lack of specific articles dealing with pre-school settings and where many of the studies in early childhood were conducted in lower primary and infant classes. Nonetheless, the report makes specific reference to those studies focusing on younger children and delineates those findings from studies of older primary school children. Articles in the ‘other’ category include studies, which in many cases provide data from pre-service or in-service teachers but do not include any intervention with learners or any evaluation of a STEAM initiative, beyond teacher opinion or attitude. These studies are useful in that they provide additional comparative insights among the key sectoral categories and provides additional data that supplement the key conclusions, particularly relating to the macro enablers and barriers to effective STEAM interventions, included at the end of the review.

Each of the research studies in the key sectoral domains were refined further based on a number of criteria. All the studies were carefully read, with notes taken to extract the key methodological and research findings. This facilitated a discrete synopsis of the details of each study. Subsequently, studies with alignment to the ‘Common Guidelines for Education Research and Development’ (NSF 2013), were identified within each sector and selected for inclusion and discussion in the final report findings. As most of the selected research was deemed foundational and exploratory, it was necessary to consider further analysis criteria to refine the final article selection for inclusion in the findings. Therefore, studies in each sectoral domain were also ranked according to Kirkpatrick & Kirkpatrick’s (2006) evaluation scale, according to the following criteria:

1. *Reaction* – How satisfied participants were with their learning.
2. *Learning* – Changes to participant learning and improvement or change to knowledge, skills, and attitudes.
3. *Behaviour* – Application of this learning, which resulted in behavioral change.
4. *Results* – Impact on organisational or societal factors related to the intervention.

Those studies which intersected on both ranking exercises formed the basis of the discussion in the findings that follow. It is important to note that most studies did not reach beyond level three on Kirkpatrick & Kirkpatrick’s ranking scale, with few studies deemed to have significant impact beyond local learning.

However, this final stage of analysis was useful in that it facilitated a fresh perspective on the initial 179 selected studies. It was agreed that where a study did not rank highly on the ‘Common Guidelines for Education Research and Development’ and/or Kirkpatrick’s levels, but had value in terms of research methodology, innovation, or creativity, that it still be considered for inclusion. Nonetheless, a caveat in the selection of these studies is that inherent limitations are discussed upfront, in addition to presenting the positive elements within the study.

One researcher focused on analysing a sector in further depth to elicit a final selection of studies from the early years/primary, post-primary, informal learning settings and ‘other’ category. The teams’ sectoral focus and selection was informed by each team-member’s contextual experience and knowledge of the research landscape in that sector. Informed by the criteria outlined above, the report brief, insights from earlier search stages, with due regard to advice from the Arts Advisory Group and the Efficacy Advisory Group, a further 86 studies were considered unsuitable for inclusion in the report.

The rationale for excluding these studies from the final report aligned with the previous five exclusion criteria and was identified specifically as:

- Duplicate studies
- The full paper could not be sourced [EC4]
- The paper did not focus on a STEAM intervention or the STEAM components in the design were not clearly elicited, or the transdisciplinary approach was beyond STEAM making STEAM effectiveness difficult to ascertain [EC3]
- Arts based element emerged as an 'add on' to the main study focus [EC3]
- Inadequate description of the intervention or the research methodology [EC5] e.g., sample size, the intervention procedure, data collection methods
- Biased design or unrepresentative or un-inclusive sample [EC5]
- Limited superficial treatment of STEAM lesson/intervention in reporting [EC5]
- Arts infused rather than arts based in approach [EC3]
- Artless STEM effect: the educational experience didn't activate the arts in any way (Clapp and Jimenez, 2016) [EC3]
- A direct instruction/procedural approach to 'teaching' the arts-based element, with no opportunities to foster authentic experiences that would develop relevant arts skills and dispositions [EC3]

The final 91 selected articles are provided in the table below by sector.

Early Years/Primary	**Post-primary**	**Informal Settings**	**Teacher Education**
60 initial	44 initial	40 initial	35 initial
34 final	**26** final	**20** final	**11** final

Table 3 - Final Selection of Research Studies for the Report

Further peer review meetings, collaboration and sharing of emergent findings preceded the writing up of sectoral findings. Where the studies could be sub-categorised by the arts-based focus and integrated STEM discipline, this provided additional structure and coherence to the report findings. The arts-based interventions were grouped by the arts focus of the study. For example, studies where there was a presentation or performative element to the intervention, such as drama, acting, music and dance were grouped as ‘Performing Arts,’ for the purposes of the review. Those studies using art forms such as painting, drawing, photography, video, filmmaking, or crafts design was categorised as ‘Visual Arts.’ Finally, the term ‘Musical Arts’ is used to discern the combination of vocal or instrumental sounds for aesthetic or form or to elicit emotion, sometimes with the use of technology but without a performative element.

Section 3: Synthesis of Results

The terms of reference guide the final discussion across the key educational sectors with disciplinary classification by 'Arts' and 'STEM' domains. The data from the set of selected studies arising from the methods outlined are summarised, compared and their results interpreted and described to draw conclusions about the primary research aims. This enables the reader to access sector and disciplinary insights by category. The findings highlight evidence-based interventions addressing STEAM education across the myriad of formal and informal settings with due regard to cultural foci, where these emerged. The discussion of findings also identifies key enablers and barriers for addressing STEAM in the early years and primary (Section A), post-primary (Section B), informal settings (Section C), and with a number of other non-sectoral studies such as those pertaining to initial teacher education, being discussed at the end of these sections. Therefore, the discussion is based on the following review domains, as required to address the key terms of reference:

- Evidence of effectiveness as a STEAM intervention
- Enablers and opportunities that support high quality STEAM learning
- Barriers and challenges to successful outcomes in STEAM education

It is important to note that where enablers and barriers to effective STEAM education are highlighted in the synthesis of results, these enablers and barriers reflect a synopsis of those opportunities and challenges identified, and consequently extracted from the selected literature.

Identification, Analysis and Evaluation of Effective STEAM Education Interventions –

Subsection A: Effective STEAM Education Interventions in Early Years and Primary Education

Initially, there were 60 papers categorised as STEAM education in early years and primary education. Following preliminary analysis a further 26 studies were not considered for inclusion in this section. The majority of the remaining studies focussed on the integration of a single arts subject with a single STEM subject. Visual arts (n=17) featured more prominently across the studies than the dramatic arts (n=13), and there were only five studies where both the visual arts and performing arts were integrated together with a STEM subject. Science was most often the STEM subject integrated with the arts (n=14), with mathematics (n=6) and technology (n=6) equally prevalent. There was only one study which featured engineering integrated with the arts.

In the following sections, the research studies that demonstrate effective interventions in STEAM education in early years and primary education are discussed. The evaluations are presented according to the art and STEM disciplines integrated, starting with the most prevalent arts, which is the visual arts.

VISUAL ARTS AND SCIENCE

The following table presents the research studies that explored the integration of visual arts and science in early years and primary education. The integration of visual arts with science was the most common approach adopted in studies of STEAM integration. There was great variety in context, approach and content across the eight studies. The early years and all primary school levels across four different continents were represented. Visual art approaches included filmmaking, painting, 3D models, tissue paper crafting, bulletin boards, scrapbooks and ‘species hotels’. Science content included climate science, geology, biology and ecology.

Visual Arts and Science	
1.	Walsh, E., Smullen, E., & Cordero, E. (2018). “My Favorite Part is When We Tell the Truth”: Identity and Agency in Middle School Youth’s Climate Science Digital Storytelling. In Kay, J. and Luckin, R. (Eds.) Rethinking Learning in the Digital Age: Making the Learning Sciences Count, 13th International Conference of the Learning Sciences (ICLS) 2018, Volume 3. London, UK: International Society of the Learning Sciences.
2.	Poldberg, M.M, Trainin, G., & Andrzejczak, N. (2013). Rocking your Writing Program: Integration of Visual Art, Language Arts, & Science. *Journal for Learning through the Arts*, 9(1), 3–20.
3.	O'Connor, G & Stevens, C. (2015). Combined art and science as a communication pathway in a primary school setting: Paper and ice. *Journal of Science Communication,* 14(4), A04.
4.	MacDonald, A., Wise, K., Tregloan, K., Fountain, W., Wallis, L. and Holmstrom, N. (2020). Designing STEAM education: Fostering relationality through design-led disruption. *International Journal of Art & Design Education*, 39(1), pp.227-241.
5.	Klopp, T.J., Rule, A.C., Schneider, J.S., & Boody, R.M. (2014). Computer Technology-Integrated Projects Should not Supplant Craft Projects in Science Education, *International Journal of Science Education*, 36(5), 865-886.
6.	Jakobson, B. & Wickman, P. (2015). What Difference Does Art Make in Science? A Comparative Study of Meaning-Making at Elementary School. *Interchange: A Quarterly Review of Education,* 46(4), 323-343.
7.	Dhanapal, S., Kanapathy, R., & Mastan, J. (2014). A Study to Understand the Role of Visual Arts in the Teaching and Learning of Science. *Asia-Pacific Forum on Science Learning and Teaching,* 15(2), 12.
8.	Caiman, C., Jakobson, B. (2019). The Role of Art Practice in Elementary School Science. *Science & Education,* 28(1-2), 153–175.

Table 4 - Evaluation of Early Years and Primary STEAM Education Literature: Visual Arts and Science

Walsh et al. (2018) present findings on their design-based research study which explores how participation in GENIE (a six-week middle school unit including lessons on climate science issues, storytelling and filmmaking) impacted students’ climate science proficiency and identity/agency. The research was funded through a grant from the National Science Foundation. It was the second pilot of GENIE and was carried out in four schools in Western/Midwestern United States. Data sources included survey assessments (n=316), as well as qualitative field notes, video-recordings of class meetings, interviews and curricular artefacts (films and science portfolios) collected from a focal sixth grade. Analysis of the pre and post survey assessments (296 students completed both the pre and post assessments) revealed gains relating to students' understanding of several aspects of climate science. No significant changes were seen from pre-test to post-test in the identity/agency instrument when the student group were analysed as a whole. The researchers attributed that finding to the diversity of the group. Subsequently, they segmented the students according to their initial interest and identification with the environment (Environment Index, (EI)). Analysing the results again with this new grouping of the students revealed a negative correlation between EI and change in EI over the course of the unit. Those who were initially identified as having low environmental interest increased EI and those who were initially identified as having high interest decreased. The case studies revealed that filmmaking gave students the space to consider and express their own personal relationship with the environment. The researchers claim that this holistic, multidisciplinary film-making experience enabled learners to put themselves in roles relating to personal and societal change that supported the development of hope, agency and engagement.

In their study, Poldberg et al. (2013) examine how the integration of art and science could foster artistic development and scientific thinking. Their research was supported by an 'Arts Education Model Development and Dissemination' Grant and a 'Toyota Tapestry' Grant. It reports on the findings of a pilot study carried out in three second grade classes in a Californian school. One class was chosen as the focus of the research due to the high implementation fidelity in that classroom. From that class, a purposive sample was selected to include a range of abilities and gender. The sample included three boys and three girls, with one of each gender from low, middle and high academic achievement levels. Three of the selected students were English Language Learners (ELL). The learning unit was designed by the teachers in collaboration with a project staff member and the education staff at the San Diego Natural History Museum. The units consisted of an introductory assembly briefing; a museum educator provided workshop followed by an unspecified number of lessons. The unit lessons addressed content standards from visual art, science and language. The visual art focus was watercolours and crayon resist, while the science focus was rocks and living things grow and change. Data sources included students' watercolour painting of a rock, students' semantic word webs and a cloze worksheet and riddle. Analysis of these student artefacts revealed that all students demonstrated increased performance in all three domains: visual arts, science and language. All students used the real rock to inform decisions they made in the creation of their artwork and were working toward proficient use of watercolour and crayon resist as set out in the second-grade visual art standards. The language art standard “writing using details in descriptions” was generally met. Finally, all students demonstrated content knowledge relating to the science content standard “Rocks have different properties” in both their artistic designs and written descriptions. Giving students a real rock (rather than an image) was highlighted as an enabler in both the creative and scientific processes as it better supported students in their observations, allowing them to identify critical attributes and physical properties.

Similar to the study by Walsh et al. (2018), O'Connor and Stevens (2015) report on the findings of a study that explores the potential for integration of the arts and climate science. This study was also a large-scale study, involving approximately 650 students and supported by funding from a government agency, in this case the Royal Society of New Zealand Marsden Fund. However, the context of both studies was different, as O’Connor and Stevens’ research reported on a project in three New Zealand schools with students ranging in age from 5-12 (a case within the larger study), and the medium used in the art pieces was manipulated tissue paper as opposed to film. Teachers, artists and scientists were involved in the delivery of the learning programme. Each iteration of the project spanned several weeks and involved a number of different schools. Each iteration began with interactive sessions facilitated by scientist and an artist followed by an unspecified number of lessons. The science focus was Antarctica, and the art focus was a tissue paper crafting. The researchers list ‘a collaborative art exhibition’ among the results of their study and propose that this tangible end product, in the form of contemporary artwork, stimulates community-based promotion of both the science and creativity involved in its creation. Evaluation of the project is limited to teacher and student feedback. This qualitative data suggests that the combined art and science approach improves student engagement in the scientific method and develops students’ understanding of “what science is”. In their research, O’Connor and Stevens identified a number of enablers that they believe led to the success of their approach: 1) using narrative rather than a didactic style of teaching humanises climate science and makes the learning feel more achievable; 2) the trajectory of the learning is guided by students’ questions and interests; 3) the use of props to create a playful classroom environment where students are learning almost without realising it.

In their research, MacDonald et al. (2020) consider an innovative STEAM learning project developed in Tasmania, an Australian state with one of the lowest levels of educational attainment, with "*entrenched teaching habits and disciplinary hierarchies often create significant barriers to the implementation of STEAM despite genuine goodwill and enthusiasm for STEAM among teachers and within schools*" (p. 227). This four-year project involves the integration of visual arts and science. Public art works, in the form of 'species hotels', were designed and constructed as creative representations of the scientific learning developed through a collaborative inquiry into the local habitat. The design process was a collaborative process involving environmental scientists, artists, designers, Greening Australia project members, art students and primary school students and their teachers. Scientists gave talks on the habitat needs of the different native species. Artists provided feedback on initial artwork designs. The primary school participants were 22-year 2/3 students. They were required to respond to the project brief through physical exploration of the site (where the public art works would be displayed) and model creation. Although no data beyond researcher observations was presented to appraise the success of the project, it is reported that due to its success it was subsequently developed and used by a number of local schools. The researchers identified various reasons for the perceived success of the project: the use of 'design' practices to link learners and bridge disciplines, collaborative engagement of experts with students as opposed to a hierarchal model. Despite the use of more varied data sources to appraise the success of this project, it was included due to the authenticity of both the science and art educational experiences it afforded.

In their study, Jakobson and Wickman (2015) examine how art activities could contribute to students' engagement with, and learning of, science. The study reports on the findings from a science lesson in a first-grade Swedish class. The 14 participants were 6-7 years old. The lesson was divided into two parts, one with a scientific purpose and one with an artistic purpose. The scientific part of the lesson involved examining leaves with a magnifier and the artistic part involved making rubbings of the leaves with crayons. Both parts of the lesson were video recorded, and the recordings were analysed using practical epistemology analysis (PEA). The findings of the study revealed that both parts of the lesson provided opportunities for cognitive and aesthetic learning. However, that learning differed in both parts of the lesson. They found that the mediating artefacts, in this case the magnifier and the rubbings', had consequences for what the children were afforded to learn. For example, the magnifier allowed the children to observe the microscopic features of the leaves, one of the leaves had “hair” whereas the rubbings activity encouraged the children to use senses other than vision, the leaves had “sticks” which they could feel. The researchers suggest that the use of these two approaches, scientific and artistic, were perhaps complementary and possible to combine. They also observed that some of the students in the class used the rubbings to create imaginative and figurative pictures, illustrating some children approached the task from an artistic point of view. Thus, the researchers conclude that having an artistic element to a science lesson does not mean the scientific focus should take precedence over the artistic.

Caiman and Jakobson’s (2019) research was conducted in a similar context to the previous study, involving a class of 6–7-year-old first graders in a Swedish school (n=24). This study also has a similar focus, in that the researchers seek to explore the role of aesthetics in enhancing students’ meaning-making in primary school science. The focus of the science lessons was animal ecology and the art practices used in the lessons were drawing and sketching using various artistic materials. The researchers chose to focus on two children and the teacher to allow them to examine those cases more closely. Data were collected through audio-recordings and field notes. Again, data analysis used practical epistemology analysis (PEA). The findings of this study revealed that art practice and science learning share common characteristics such as making predictions and doing meticulous observations. The researchers also found that imagination and creativity, key elements of art practice, support children’s meaning-making when they are exploring complex phenomena. These commonalities were shown to be of significance in deepening children’s scientific understandings; a finding which reflects those of Jakobson and Wickman (2015).

Dhanapal et al. (2014) present findings on their research which explores the role of visual arts in science teaching and learning. 31 third-grade students and four teachers in an international school in Malaysia participated in this study. One science lesson, of two of the four participating classes, which incorporated a visual art component was video recorded. The focus of the science lessons taught were not specified in the paper. The visual art focus included creating 3D models, dioramas, and drawing. Qualitative data were collected in the form of student questionnaires, teacher questionnaires and observation. The teachers expressed the view that the integration of different visual art elements with science is beneficial as it affords their students greater flexibility to choose the form of art that best supports them in expressing their learning of science. They reported increased motivation and improved communication in lessons which integrated the visual arts and science. The students also reported enjoying the variety of integrated art-science lessons they had experienced, they included constructing 3D models, making dioramas of habitats and creating drawings of living things. Like the Andrikopoulou and Koutrouba (2019) study, this study was included to ensure the student and teacher voice was represented. However, it has similar limitations to the aforementioned study, in that the research used self-reported data only and relatively little information was provided on the instructional approaches used by the teachers.

Klopp et al. (2014) compare the use of craft-based projects and technology-based projects in the teaching of science concepts. The participants of the study were 28 academically advanced students in Grades 2-7 who attended a school in rural Iowa. The students attended lessons with a teacher who specialised in education of the gifted for a minimum of 2.5 hours a week over an eight-week period. During those eight weeks they completed four units (each spanning two-weeks), with each unit focussed on a different fossil organism. Two of those units required students to create a craft-based project to support their learning and the other two units required the creation of a technology-based project. The craft-based projects included the creation of bulletin boards, scrapbooks, or 3-D paper objects. The technology-based projects included movies and narrated slideshows. Two rubrics were created to assess each project on creativity characteristics and academic aspects. Student ratings of the learning approaches were also collected to assess the affective characteristics of the approach. Students demonstrated higher levels of creativity when working on the technology-based projects than they did while working on the craft-based projects.

However, students perceived themselves to be more creative when they were making crafts and preferred working on the craft-based projects. The researchers suggested that this might stem from the students having a narrow view on creativity. More academic content was included in the craft-based projects than the technology-based projects. The technology-based projects tended to focus more on drama and humour rather than the science content whereas the crafting was a more deliberate and serious process for these students.

Enablers in Visual Arts/Science - Early Years/Primary	Barriers in Visual Arts/Science - Early Years/Primary
• Having a 'holistic' multidisciplinary approach • Projects being led by protagonists that have experience creates greater 'buy-in' from students • Student-directed learning generates a learning legacy • Drawing on ideas and values that were of personal, family or community consequence • A range of communication pathways rather than a didactic style of teaching • Using narrative-based learning to humanise the learning and make it seem more achievable • The trajectory of learning is steered by student questions • The use of props to create a playful classroom environment where students are learning almost without realising it • The importance of observation to both disciplines provides the perfect opportunity for integration of art and science • Objectives from each discipline integrated into the project design from the beginning • Negotiations with student peers and educators over positions of authoring and power • Exploring STEAM using real-world problems located within students' social, cultural, ecological contexts	• Difficulty in ensuring equality of experience due to varying expertise among educators • The lack of a formal curriculum • The demands on educators to be 'experts' in an expanding number of areas • Discipline hierarchies among stakeholders that can lead to the privileging of one or more disciplines over another • Negotiations with student peers and educators over positions of authoring and power • Approaches where the art is driving the science rather than the other way around are less readily understood • A narrow view of creativity

Table 5 - Enablers and Barriers Identified in Visual Arts-Based/Science Literature in the Early Years and Primary Education Sectors

VISUAL ARTS AND MATHEMATICS

In this section, the research studies that explored the integration of visual arts and mathematics in early years/primary education are presented. The visual art approach and mathematics topic varied from study to study. The visual art elements included were visual art perception, drawing, painting, design, and collage-making. The mathematics topics taught in the interventions varied greatly, spanning four of the primary mathematics curriculum strands: number, measure, shape and space and algebra.

Visual Arts and Mathematics	
1.	Schoevers, E., Leseman, P., & Kroesbergen, E. (2019). Enriching Mathematics Education with Visual Arts: Effects on Elementary School Students' Ability in Geometry and Visual Arts. *International Journal of Science and Mathematics Education,* 18(8).
2.	Brezovnik, A. (2015). The Benefits of Fine Art Integration into Mathematics in Primary School. *CEPS Journal: Center for Educational Policy Studies Journal*, 5(3*)*, 11-32.
3.	Ariba, O., & Luneta, K. (2018). Nurturing Creativity in Early Years' Mathematics via Art-Integrated Mathematics Lessons. *The International Journal of Early Childhood Learning*, 25 (2), 31-48.

Table 6 - Evaluation of Early Years and Primary STEAM Education Literature: Visual Arts and Mathematics

In their study Schoevers et al. (2019), report on the effects of the Mathematics, Arts, and Creativity in Education (MACE) programme on fourth, fifth and sixth grade students' geometric and visual art abilities. The MACE programme is a series of nine lessons aimed for 4^{th}-6^{th} grade students in which geometry and the visual arts are integrated. This was a large-scale study, involving 2909 students from 21 3^{rd}-6^{th} grade classes from 57 schools. The researchers adopted a quasi-experimental design with two experimental groups and one control group. The first experimental group were taught the MACE programme by teachers following a professional development program. The second experimental group were taught the lessons from the MACE programme by a teacher who was not following the professional development program. The control group were taught a series of traditional geometry lessons. For logistical reasons, participating schools were assigned to the groups based on the proximity, and hence accessibility, of the professional development facilities to their schools. Three instruments were used to collect data on the participants pre and post intervention: a Geometric Ability Test (GAT), a Geometric Creativity Test (GCT) and a Visual Arts Assignment. Two versions of the GAT and the GCT were developed; one version was used in the pre-test and one in the post-test. The same visual arts assignment was used in both the pre-test and post-test. Contrary to researcher expectation, the findings of the study revealed that students from all groups demonstrated improved understanding of and ability to explain geometrical concepts and geometrical creative thinking. No significant difference was found between the experimental and control groups. One reason proffered for the lack of difference between groups was that teachers of the control groups indicated that while the lessons they taught were similar to regular geometry lessons, they had included more student interaction than usual. They also highlighted the relatively short intervention (nine lessons) as a limiting factor. However, significant differences between classes were apparent in their ability to describe geometrical aspects in visual artwork. Those students who were taught using the MACE programme improved more than the students in the control group from pre-test to post-test.

Like Schoevers et al. (2019), Ariba and Luneta (2018) examine the effect of art-integrated mathematics lessons on students' creativity in mathematics. The researchers employed a purposive sampling technique to select participants between 0 and 6 years, "the creative years" as determined by a review of the literature. Two classes of grade 1 students from two schools in Nigeria were selected as participants in the study. A pre-test post-test control group design was adopted for the study. The students from the grade 1 class in one school (n=9) were assigned to the experimental group and the students from the grade 1 class in the other school (n=6) were assigned to the control group. The experimental group participated in art-integrated mathematics lessons, using subservient integration; that is, the art concepts were solely used to support children's understanding of the mathematical concepts. The control group were taught using traditional lessons. Both groups participated in their respective lessons over a twelve-week period. The mathematical concepts taught were counting, addition, subtraction, more than/less than, and the identifying, collecting, and sorting of shapes. The visual art forms integrated into the mathematics lessons of the experimental group were drawing, painting, design, and collage-making. Two data collection instruments were used in this study: the Creativity Assessment Tool (CAT), whose dependability had been tested in previous trials

(Lucas, Claxton and Spencer, 2012; 2014 and Lucas, 2016), and a pre-test and post-test construct, that involved a pre-test examining learners' creative dispositions in mathematics. While the pre-test was administered to participants prior to the commencement of the intervention, the post-test was administered on completion of the intervention. All the mathematical lessons taught during the intervention were video recorded. Data analysis showed no substantial difference between the pre-test and post-test scores of the two groups after the intervention. However, results from the CAT revealed a greater enhancement of all creative dispositions for learners in the experimental group when compared with their counterparts in the control group. Therefore, the researchers concluded that integrating art into mathematics lessons fosters the creative dispositions of young learners. The researchers felt that though the relatively short intervention period (12 weeks) may have been enough time to cultivate creativity, it was not enough time for creativity to flourish.

Brezovnik (2015) conducted research on the impact of integrating fine arts and mathematics on students' achievement in mathematics. The research was conducted in ten randomly selected Slovenian classes. 210 fifth grade students attending primary schools participated in this research study. 105 were assigned to an experimental group and 105 were assigned to a control group. While both groups were considered of similar mathematical ability before the intervention, the experimental group had received higher average scores in their fine arts programme the previous year than those students in the control group. This should be taken into consideration when evaluating the impact of the intervention. Students in both groups were simultaneously taught four new mathematical concepts: equations, inequalities, powers and perimeter. The students in the experimental group received instruction in mathematics with the incorporation of fine art. Artistic balance was explored with equations, artistic imbalance with inequations, rhythm with powers and architectural space with perimeters. Students in the control group were taught in the traditional way. The length of the intervention or number of lessons taught was not reported. The students in both groups sat a mathematics test after each unit of study to determine if there were any discernible differences in knowledge between the experimental and control groups. Prior to their use in the study, the sensitivity, reliability and validity of the mathematics tests were confirmed. The results of the study showed that the integration had a statistically significant effect on students' mathematical achievement across all four mathematical topics. Students in the experimental group achieved significantly higher marks in all four of the mathematics tests than the control group. The greatest differences between the experimental group and control group were observed in the mathematical topic of powers and the least difference observed in the mathematical topic of perimeter. It was proposed that this difference could be attributed to the more visual nature of this mathematical topic, suggesting that certain mathematical topics lend themselves more readily to integration with the arts. From these results, the researchers concluded that there was a positive impact on mathematical achievement from the integration of fine arts and mathematics.

Enablers in Arts/Mathematics – Early Years/Primary Education	**Barriers in Arts/Mathematics — Early Years/Primary Education**
• Learning from personally constructed experiences and activities • Teaching in an integrated way saved time in an overloaded curriculum and afforded more time to developing creativity. • The arts can support students to see the challenge, beauty, playfulness and utility of mathematics • Certain mathematical topics are visual by their nature and therefore lend themselves more readily to integration with the arts • Mathematical creativity and artistic creativity can complement and reciprocate one another • Focussing on one concept over a series of consecutive lessons rather than spread out over a school year led to deeper understanding	• Variations in expertise and favoured teaching style that is incompatible with STEAM learning • Ingrained view of art as a recreational subject • Limited time available for STEAM education and to nurture creativity

Table 7 - Enablers and Barriers Identified in Arts-Based/Mathematics Literature in the Early Years and Primary Education Sectors

VISUAL ARTS AND TECHNOLOGY

This section presents the research studies that explore the integration of visual arts and technology in early years/primary education. The technological tools used in the studies included soft circuits, Kibo (a robotics kit), and 3D model design software and 3D printers. The visual art form varied from felted toys and characters crafted from recycled materials to utility products.

Visual Arts and Technology	
1.	Yliverronen, V., Rönkkö, M.-L., & Kangas, K. (2021). Learning everyday technologies through playful experimentation and cooperative making in pre-primary education. *FormAkademisk - Forskningstidsskrift for Design Og Designdidaktikk*, 14 (2).
2.	Sullivan, A., Bers, M.U. (2018). Dancing robots: integrating art, music, and robotics in Singapore's early childhood center. *International Journal of Technology and Design* Education, 28, 325–346.
3.	Leinonen, T., Virnes, M., Hietala, I., & Brinck, J. (2020). 3D Printing in the Wild: Adopting Digital Fabrication in Elementary School Education. *International Journal of Art and Design Education,* 39(3), 600-615.

Table 8 - Evaluation of Early Years and Primary STEAM Education Literature: Visual Arts and Technology

Yliverronen et al. (2021) conducted their research in a pre-primary setting in Finland as part of a larger research project InnoPlay. This larger research project aimed to develop pedagogical approaches that integrate design, technology and mathematics to motivate learners from kindergarten to second grade. The project reported on by Yliverronen et al. (2021) focussed on teaching children about the basics of technology while creating a craft product. The research was carried out over a four-month period with a group of 19 children aged 5-6 years, who were attending a Finnish preschool. The project was planned and implemented by the pre-school manager, two early childhood teachers and their assistants with support from the researchers, a project worker of the InnoPlay project and on occasion parents and older students. The 19 children participated in 20 sessions of 30-60 minutes each. Initial sessions focussed on introducing the children to the relevant concepts, followed by sessions focussed on the design and construction of their project before the culminating session, an exhibition to display the works of art. Data were collected through video-recordings of the orientation, design and construction phases, children's sketches and designs, and the completed projects. Qualitative content analysis was employed to elicit meaning from the data. The results of the study revealed that all of the children were able to construct original craft products with soft circuits according to their pre-determined design. The operational culture of early childhood care and education (ECCE) settings, which includes cooperation between personnel, family and the local community, was highlighted as a contributor to the success of the project. The use of play-based pedagogies was also endorsed as suitable learning approaches, to support the development of pre-primary students' STEAM understandings.

Similarly, Sullivan and Bers' (2018) study explores how technology and visual arts could be integrated in the pre-primary classroom. Their research involved children aged between three and six (n=98) from five preschools in Singapore, who engaged in a seven-week robotics and programming curriculum called "Dances from Around the World". The research was funded through a grant from the National Science Foundation. Each week the children learned a new programming concept with the 'Kibo' robot. The 'Kibo' robot has an art platform that allows children to personalise their robots with craft materials. The goal of STEAM education in Singapore is not only to develop technical knowledge but also to develop soft skills such as collaboration, communication and creativity. Hence, the researchers were interested in collecting data on the children's mastery of programming concepts and the frequency of children's positive behaviours while participating in the curriculum. To do this they employed a mixed-method design collecting both quantitative (programming mid-test and post-test scores and frequency of behaviours observed) and qualitative (teacher interviews and journals) data. Only five of the programming concepts were assessed in both the mid-test and post-test (easy sequencing, hard sequencing, easy repeat numbers, hard repeat numbers, wait for clap) as the more advanced concepts had not been covered yet. Of these five concepts there was a statistically significant increase in students' scores from mid-test to post-test on the 'easy sequencing' and the 'wait for clap' tasks. Results from the post-test indicated a high level of mastery on all programming concepts taught, including more advanced concepts such as iteration and conditional statements. This was perhaps due to the hard work of the teachers who ensured they gained hands-on experience of using the technology before they taught the lessons. They highlighted that hands-on training experiences in the use of the technology were more valuable than online resources. The researchers also measured the frequency of children's positive behaviours while participating in the curriculum. The results showed that the curriculum was most successful at cultivating students' content creation, communication and collaboration. Creativity also had a relatively high score. However, unlike the Yliverronen et al. (2021) study, the approach adopted in this study did not lend itself to finding ways to engage with the greater school community. Results from the teachers' interviews and journals indicated that the initiative was a positive experience for both the students and teachers involved.

Leinonen et al. (2020) use an ethnographic research design to explore how 3D design and printing has been introduced in multidisciplinary learning modules in primary education. This work was part of the *Pänttäyksestä printtaukseen* project, funded by the Finnish National Agency for Education (EDUFI). The participants of the study are 4 teachers and 64 children from 4th-6th grade in a Finnish elementary school. The fourth and fifth grade students participated in four 2 x 45-minute sessions and the sixth graders participated in five 2 x 45-minute sessions. The first session was an introductory session, explaining the industry and showing some examples. Next students were introduced the Tinkercad Design software and some design tasks. Self-design became more prominent as the project progressed. The final task involved the design of a functionable product. The design topics taught each week were the same for all students e.g. utility products or game pieces, but students were encouraged to create an original 3D design by applying their own ideas and creativity.

Data were collected through informal interviews, field notes and a questionnaire. Results of the study indicate that learning during the initial 3D printing activities, centred on the usage of the 3D tools and technical skills. This had a limiting effect on the extent to which the students were able to use their creativity and develop design thinking skills. The researchers suggested that to facilitate the creative process more time should be dedicated to sketching and prototyping.

However, the researchers did note that the creation of a personally relevant artefact and the novelty of using a modern technology were both empowering and motivating for the children involved in the study.

Enablers in Arts/Technology – Early Years/Primary	**Barriers in Arts/Technology – Early Years/Primary**
• Use of play-based pedagogies • Cooperation between personnel, family and the local community • The integration of technology does not necessitate passive screen time • Creating a personally relevant piece of artwork increasing children's empowerment • Increased emphasis on social interactions and collaboration • Self-motivated teachers who gained practical experience of using the technology before the lessons. • The novelty of using modern technology can arouse curiosity and generate motivation • Hands-on training experiences were more valuable than online resources	• Inadequate time dedicated to sketching and prototyping • Inadequate funding for quality technological tools • Lack of provision of adequate quality professional development • Impact of inappropriate teaching style, pedagogical approach and interpretation of the curriculum • Variety of digital tools available – do not all produce similar learning achievements • The need to adapt resources to suit teaching contexts • The need to develop technical skills first to enable integration

Table 9 - Enablers and Barriers Identified in Arts-Based/Technology Literature in the Early Years and Primary Education Sectors

Visual Arts and Engineering

There was only one research study that explored the integration of the arts and engineering in early years/primary education. The project had a visual art focus.

Visual Arts and Engineering	
1.	DeJarnette, N. (2018). Early Childhood Steam: Reflections from a Year of Steam Initiatives Implemented in a High-Needs Primary School. *Education,* 139 (2), 96-112.

Table 10 - Evaluation of Early Years and Primary STEAM Education Literature: Visual Arts and Engineering

In her research, DeJarnette (2018), explores the impact of implementing a STEAM initiative in a high-needs primary school in the United States. The participants of the study are two teachers and their classes, the school librarian and the school arts-instructor. They are responsible for teaching the STEAM curriculum to 300 children in grades K-2. The curriculum implementation consisted of a series of engineering design projects based on children's literature. The art focus involved the use of various mediums in the design and decoration of the engineering projects. The students engaged in two engineering projects a month between October and May. Each project involved a read aloud session, after which an engineering problem was posed, and an art session where students constructed and tested their designs. Data collection methods included surveys, interviews and field notes. Results from the study showed that young children are capable and enthusiastic STEAM learners. Not only could they successfully grapple with engineering design problems, but they were able to grasp foundational STEAM concepts that impacted their designs. They enjoyed having an opportunity to engage in creative tasks. The teachers reported that the learners improved in several aspects over the course of the initiative including, thinking critically and identifying ideas for a design solution and revising their designs following testing.

The study also reported an increase in teachers' self-efficacy in their own ability to implement STEAM lessons. The researcher provided considerable support to the teachers throughout the initiative: she developed the curriculum, provided the materials and books (purchased through a university research grant) and modelled full STEAM lessons. Both teachers acknowledged the importance of that support, and at the end of the initiative indicated that although they felt more confident now, they did not feel ready to implement STEAM curricula independently.

Enablers in Arts/Engineering – Early Years/Primary	Barriers in Arts/Engineering – Early Years/Primary
• Teaching consecutive lessons on topics rather than long periods between lessons • Young children are natural explorers • Collaboration between various stakeholders • Feelings of intimidation and negative dispositions can be overcome by positive experiences and support.	• Difficulty in defining engineering – what is considered art and what is considered engineering in early education settings? • Significant amount of time required for professional development • Inadequate availability of resources and materials • Lack of support during implementation • Low levels of self-efficacy of the teachers implementing the STEM

Table 11 - Enablers and Barriers Identified in Arts-Based/Engineering Literature in the Early Years and Primary Education Sectors

PERFORMING ARTS AND SCIENCE

This section presents the research studies that explore the integration of performing arts and science in early years/primary education. The integration of creative drama was the most common approach to integrating performing arts and science in studies of STEAM integration in early years and primary education (n=3). Dance was integrated with science in the two other studies. There were no examples of music and science integration in the early years/primary education literature.

Performing Arts and Science	
1.	Young-Mi, K. & Hye-Jeon, H. (2016). The effects of “Physics, Let’s Dance,” as an integrated dance art education program related to science subject, on the personality and creative thinking ability of elementary school students. *Indian Journal of Science and Technology*, 9(29).
2.	McGregor, D. (2014). Chronicling innovative learning in primary classrooms: Conceptualizing a theatrical pedagogy to successfully engage young children learning science. *Pedagogies: An International Journal*, 9(3), 216-232.

3.	Maharaj-Sharma, R. (2018). Drama in Science Teaching – An example from Trinidad and Tobago. *The Electronic Journal of Science Education,* 22(4), 19-34.
4.	Hendrix, R., Eick, C.J., & Shannon, D.M. (2012). The Integration of Creative Drama in an Inquiry-Based Elementary Program: The Effect on Student Attitude and Conceptual Learning. *Journal of Science Teacher Education,* 23(7), 823-846.
5.	Bassachs, M., Cañabate, D., Nogué, L., Serra, T., Bubnys, R. and Colomer, J., (2020). Fostering Critical Reflection in Primary Education through STEAM Approaches. *Education Sciences,* 10(12), 384-398.

Table 12 - Evaluation of Early Years and Primary STEAM Education Literature: Performing Arts and Science

Young-Mi and Hye-Jeon (2016), investigate the effect of a performing arts and science programme, “Physics, Let’s Dance”, on the creative personality and thinking ability of elementary students. 30 first and second grade students from a South Korean school were randomly assigned to an experimental or control group. The 15 students assigned to the experimental group attended the integrated science and art of dance class, while the 15 students in the control group attended a science experiment class. Both groups attended fifteen, 3-hour sessions of their respective class over a three-month period. The researchers employed a quasi-experimental design, with both groups undertaking a creative personality test and a creative thinking ability test before and after the intervention. The creative personality test investigated six factors: curiosity, self-assurance, imagination, patience/obsession, spirit of independence and spirit of adventure. The creative thinking ability test measured four factors: fluency, originality, elaboration and abstractness of titles. Analysis of the pre-tests revealed the homogeneity of both groups with respect to their creative personality and thinking ability, prior to the commencement of the intervention. The findings of the study revealed significant differences for the experimental group from pre-test to post-test in all aspects of creative personality and thinking ability. The researchers did recognise that difference in creative personality and thinking ability could be attributable to individual differences and recommended that it would be necessary to examine these differences by personal characteristics in the future. The researchers highlighted the importance of finding natural opportunities for integration rather than forced or contrived integration. In their study, they chose to explore motion, a point of intersection between science and dance.

Bassachs et al. (2020) also explore the possible benefits of integrating Science and dance. This research was funded by grants from 'FECYT', 'Spanish Federation for Sciences and Technology and the Institute of Sciences Education', Josep Pallach, University of Girona. Their research study involved 90 students from first grade, third grade and fifth grade classes in a Spanish primary school. Five researchers, a specialist physics teacher and a specialist dance teacher were responsible for supervising the implementation of the educational approach. Similar to the previous study, concepts related to motion were the focus of the learning. In dance these included rhythm, use of space, speed and acceleration while in science topics included forces, energy and equilibrium. The educational approach consisted of six stages: stage one involved activating prior scientific knowledge; in stage two the students carried out six science experiments; stage three involved students reflecting on their new learning; in stage four the students translated those scientific variables into physical variables, in stage five they used artistic movement to explain those scientific concepts and in stage six students engaged in open group discussions reflecting on their experience. The group discussions were facilitated by a member of the research team with support from a teacher. During these discussions, students were asked to reflect on their acquisition of scientific and artistic concepts as well as their development of personal competences, skills, beliefs etc. The data collection method was video-recordings of these group discussions. These video recordings were then analysed using the Kember et al. (2008), four levels of reflection: descriptive, argumentative, reflective and critical reflective. Each of these levels was then assigned a numerical value calculated by quantifying the number of occurrences of comments on each level in the areas of science education and dance education. The results of the study show that while the first graders mostly reflected at the descriptive level, levels of critical reflection were high among both the third and fifth graders. The researchers concluded that the high levels of critical reflection among these students demonstrated that the physics-dance approach was effective in developing students' understandings of both science and artistic concepts.

However, this study was not as rigorous as the previous study, there was no control group and no pre-test data meaning the levels of criticality demonstrated by the students cannot be definitively attributed to the intervention. The emphasis placed on dance is also difficult to discern. The researchers mention the fostering of artistic competences (e.g. using the expressive resources of the body to communicate creatively) but the description lacks detail on how this was achieved. Negative attitudes and competences of teachers was highlighted by the researchers as a potential barrier to successful implementation.

McGregor (2014) reports on the findings of a project which explored the impact of applying dramatic techniques in the teaching of science. Dramatic techniques explored in this study include both ‘unscripted’ dramatic techniques such as role-play and improvisation and ‘scripted’ dramatic techniques such as monologues or mini-historical plays. 17 teachers and 256 students aged between ages 8-11 from 12 UK schools participated in the study. Participating teachers attended five professional development workshops over three school terms. The professional development workshops introduced and reinforced scientific understandings, demonstrated pedagogical strategies utilising dramatic techniques, and provided participants with opportunities for enactment and reflection. These teachers then experimented with the techniques in their classrooms, exploring how they could impact their practice and their students’ understanding of science. The researchers then used a mixed-method approach to evaluate the impact of the intervention on the teachers’ practice and the students’ understanding of science. Data were collected through teacher (pre and post) and student questionnaires, teacher reflective journals, field notes and focus group discussions. The reflections, field notes and observations showed that the teachers were successful in applying the dramatic techniques in their classes. Teachers reported that the innovative pedagogies engaged and motivated the students, piquing their interest in science, while also allowing lessons to be more inclusive. Nearly 75% of students reported believed that acting out their ideas benefitted their science understandings and most students believed that it made their science learning more fun. The students also believed the drama-based teaching helped them better understand many aspects of scientific enquiry including thinking of new ideas, testing ideas, making observations and seeing patterns. Improvements in students’ conceptual and procedural understandings were also reported. Monologues of scientists were identified by teachers as a rich resource in generating opportunities for authentic inquiry. They also emphasised the importance of persisting with the new strategies and giving the students ample time to adapt.

Maharaj-Sharma (2018) also evaluates the impact of drama-based instruction on primary school children’s science understandings. This study adopted a quasi-experimental design to investigate the effect of drama-based instruction on the achievement and attitude towards science of a group of primary school students (aged

9-11) in a Trinidadian school. The study sample included 43 students from two classes who were taught by the same science teacher. The classes were randomly selected as the experimental group and the control group. Both groups completed a Summative Achievement Test (SAT) and an Attitude Towards Science (ATS) prior to the commencement of the intervention to determine their prior scientific knowledge and attitudes towards science. There were no statistically significant differences between the pre-test scores of the experimental group and the control group. Both groups then participated in five, 45-minute lessons on Forces over a two-week period. The experimental group were taught using creative drama instruction. The lessons taught to the experimental group were developed with support from a science professor and a drama teacher and had been piloted with another class in another school. The control group were taught using traditional instruction methods including textbook instruction and whole class discussion. The SAT and ATS instruments were administered to both groups again after the intervention. Both groups showed a significant improvement with respect to the SAT from pre-test to post-test. However, the observed improvement for the experimental group was greater than that of the control group. Analysis of the ATS pre and post-test scores of both groups revealed that while there was little change in attitudes towards science for the control group, there was a positive shift in attitudes towards science for the experimental group suggesting the drama-based instruction had an impact on their attitude towards science. The researchers believed that elements of drama-based instruction such as active learning, autonomy and social interaction were key enablers in this intervention. The multi-disciplinary team ensured the integrity of both drama and science was upheld. The authors recognise the limitations of their study given the small sample size but put their research findings forward as a starting point to provide motivation for more structured formal research.

Hendrix et al. (2012) employed a similar quantitative, quasi-experimental, pre/post-test design in their study of the impact of creative drama on student achievement and attitude to science in the United States. While the participants of this study were of a similar age to those in Maharaj-Sharma’s study, they differ in that they were all identified as ‘talented and gifted’ learners by their school system. The 38 participants were members of two enrichment classes of fourth grade students and two enrichment classes of fifth grade students. One fourth grade class (n=9) and one fifth grade class (n=10) were selected as the creative drama experimental groups and one fourth grade class (n=12) and one fifth grade class (n=7) were selected as the study’s non-drama control groups. All fourth-grade students were taught the Full Option Science System

(FOSS) modules of sound solar energy while all fifth-grade students were taught the Full Option Science System (FOSS) modules of solar energy. Creative drama activities were integrated into these modules in classes of the experimental groups. The creative drama included skits, improvised songs, puppet play, creative movement, characters, and props. The primary researcher, who was certified in both education and drama, developed the creative drama activities and taught both the science and creative drama. Changes in science learning outcomes were measured by the pre and post-tests included with the FOSS modules while changes in attitudes to science were measured using the Three Dimension Elementary Science Attitude Survey (TDSAS) which was administered at the beginning and the end of the investigations. A mixed ANOVA was performed to examine differences in learning outcomes and attitudes toward science between groups. Students in the experimental groups had significantly higher learning gains than students in the control groups, while the learning gains of the fourth-grade students were significantly greater than those of the fifth grade students. This showed that the integration of creative drama and science led to positive gains in scientific understanding. The availability of a supportive/adaptive curriculum and the expertise of the teacher benefitted this arts/science integration intervention. Contrary to the findings of Maharaj-Sharma (2018), there was a small but statistically significant decrease in student attitudes toward science across all groups. However, the researcher noted that despite the slight decrease from pre-test to post-test, the students' attitudes were still at the high end of the attitude survey, so still very positive.

Enablers in Performing Arts/Science – Early Years/Primary	Barriers in Performing Arts/Science – Early Years/Primary
• Input from professionals in the performing arts stimulates creative imagination • Finding opportunities for natural integration – points of intersection between the arts and science • Availability of expertise and talent to support projects • Monologues were a rich resource in generating opportunities for authentic inquiry • Persisting with and allowing children time to adapt to new methodologies • Multi-disciplinary team involved in the project • Availability of supportive/adaptable curricula	• Negative attitudes and competences of teachers • Over emphasising one disciplinary area to the detriment of the other • Lack of motivation, professional development and support

Table 13 - Enablers and Barriers Identified in Performing Arts/Science Literature in the Early Years and Primary Education Sectors

PERFORMING ARTS AND MATHEMATICS

This section presents the research studies that explored the integration of performing arts and mathematics in early years/primary education. Two of the studies integrated drama and mathematics and one explored dance-science integration. The mathematics concepts spanned the number, shape and space and measures strands. A wide variety of drama-based approaches were adopted from teacher in role to soundscape. The dance concepts explored in the dance-science intervention were body, space, energy and relationship.

Performing Arts and Mathematics

1.	Leandro, C., Monteiro, E., & Melo, F. (2018). Interdisciplinary working practices: can creative dance improve math? *Research in Dance Educatio*n, 19(1), 74-90.
2.	Duman, B. & Özçelik, C. (2018). The Effect of the Creative Drama-supported Problem-based Learning Approach on the Self-efficacy Ability in Geometry. *Universal Journal of Educational Research,* 6(12), 2918-2924.
3.	Coleman, C., & Davies, K. (2018). Striking gold: Introducing Drama-Maths. *Teachers and Curriculum, 18*(1), 9-18.

Table 14 - Evaluation of Early Years and Primary STEAM Education Literature: Performing Arts and Mathematics

Leandro et al. (2018) explored the use of creative dance in the teaching and learning of mathematics concepts using a quasi-experimental design. The study sample was 117 second grade students in two Portuguese schools. There were eight classes altogether, five classes were assigned to the experimental group and three were assigned to the control group. The intervention was conducted over a four-month period between January and April, in three phases the content acquisition phase, the content consolidation phase, and the content retention phase. In the first phase, both groups were taught mathematical concepts. The mathematics concepts included decimals, operations, money and time. In the second phase, the experimental groups participated in four creative dance sessions which explored the relationships between movement elements and the mathematical concepts. The dance concepts were body, space, energy and relationship. The dance lessons were critiqued by a specialist dance teacher before they were taught. The control groups participated in four mathematics consolidation sessions using the traditional methodology. Both groups were tested at three points during the intervention: pre-test, post-test and re-test (one month later). Analysis of variance and paired sample t-tests revealed that the experimental group had significantly lower results than the control group in the pre-test but then out-performed them in both the post-test and re-test. The paired sample t-tests also showed a significant difference between pre-test and post-test scores of the experimental group. Comparison of the post-test and re-test scores confirmed that this improvement was maintained in the post-test stage. Therefore, the researchers concluded that the integration of mathematics and creative dance proved more effective in the consolidation of mathematical concepts and stabilising of knowledge retention than the traditional methods.

Duman and Özçelik (2018) sought to determine if creative drama was effective in supporting problem-based learning in geometry classes. The researchers employed a pre/post-test control group experimental design in their research. The study group was 59, fifth grade students in a Turkish elementary school. Following cluster analysis, 42 students were selected to participate in the study, 21 in the experimental group and 21 in the control group. The intervention was carried out over a six-week period, in which both groups participated in twenty lessons (five hours per week). The students in the experimental group were taught using a creative drama-based problem-based learning approach and the students in the control group were taught using the existing curriculum. The drama approach involved the enactment of scenarios. The researchers mentioned the importance of evaluating the development of dramatic understandings, but no detail was provided on how this was done. Therefore, drama appears subservient to the development of mathematical understandings. The instrument used in the pre-test and post-test was developed by Cantürk-Günhan and Başer (2007) and collected data on the geometry self-efficacy beliefs of the students. It had previously been tested for validity and reliability with a group of 385 primary school students. Paired sample t-tests and independent sample t-tests were performed to determine if there was a significant difference between the groups and results achieved in the pre-test and post-test for both groups. While the geometry self-efficacy beliefs of students in the control group and the experimental group were found to be equivalent before the intervention, significant differences were observed for both groups from pre-test to post-test. However, their findings showed that the creative drama-based problem-based learning approach was more effective than the existing curriculum in developing geometry self-efficacy beliefs, particularly those self-efficacy beliefs relating to the use of geometry. The researcher highlights student-centred and constructivist approaches as central to this development.

Coleman and Davies (2018) also explored the use of drama in the teaching of mathematics. However, they employed qualitative data collection techniques in their research on STEAM integration. The participants in this study were 10 year 3 and year 4 students attending a mid-decile primary school in New Zealand. Six drama-mathematics lessons were taught, twice a week over a three-week period. The lessons were predominantly taught by a non-drama specialist teacher. The mathematical concepts taught included multiplication, division and fractions and the drama techniques used included teacher in role, blanket role, role on the wall, freeze frame, flashback, thought tapping, soundscape, slow motion and mapping. Data were collected through semi-structured focus group interviews, participant observation and critical friend discussions. The study revealed the value of incorporating imagination into mathematics as it increased students' enjoyment of and interest in the mathematics lesson. In this study, participants used techniques and elements of drama to create and sustain a fictional context during the lessons. The researchers reported that this fictional context added value and relevance to the mathematics which resulted in students being more motivated to persevere and find a solution. The use of drama-based instruction also resulted in a shift in the power dynamics between the teachers and students. This resulted in greater levels of agency and responsibility than would traditionally be experienced in the classroom. The researchers recognised that the wishes of key stakeholders to ensure the primacy of mathematics in the intervention and limited time afforded to the intervention as key barriers.

Enablers in Performing Arts/Mathematics – Early Years/Primary	**Barriers in Performing Arts/Mathematics – Early Years/Primary**
• Intervention focuses on the development of both mathematical and artistic understandings • Opportunities for the development of creativity • Support from specialist teachers • The use of student-centred and constructivist approaches • Use of an imagined narrative to provide 'real' problems • Adopting a playful approach	• Performing arts being positioned as subservient to STEM discipline • Didactic teaching methods • Key stakeholders reinforcing the primacy of the STEM subject • Limited time afforded to drama-based lessons

Table 15 - Enablers and Barriers Identified in Performing Arts/Mathematics Literature in the Early Years and Primary Education Sectors

PERFORMING ARTS AND TECHNOLOGY

This section discusses the research studies that explored the integration of performing arts and technology in early years/primary education. Both studies explore the integration of music and technology. The technology used in one was Scratch and Raspberry Pi, and the other study used MIROR Impro. The musical focus of the first study is unclear, while the second study included both listening and creating activities.

Performing Arts and Technology	
1.	Sáez-López, J.M & Sevillano-García, M. L. (2017). Sensors, programming and devices in Art Education sessions. One case in the context of primary education. Cul*ture and Education, 2*9(2), 350-384.
2.	Lagerlöf, P., Wallerstedt, C., & Pramling, N. (2013). Engaging children's participation in and around a new music technology through playful framing. *International Journal of Early Years Education*, 21(4), 325-335.

Table 16 - Evaluation of Early Years/Primary STEAM Education Literature: Performing Arts and Technology

Sáez-López and Sevillano-García (2017) present findings on their research exploring the possibility of integrating computational thinking and art education by employing technological resources such as Scratch and Raspberry Pi. 109 sixth class students in four Spanish schools were assigned to an experimental group and 35 students from two schools were assigned to a control group. Both groups engaged in an equivalent teaching unit of twenty sessions over the course of an academic year. The control group learned with musical instruments whereas the experimental group learned with Scratch, Raspberry Pi and sensors. The experimental groups created a series of projects using both the multimedia features of Scratch and external hardware like PicoBoards that allowed them to interact with instruments. Quantitative data were collected from both groups of students by means of a questionnaire and qualitative data were collected from the teachers by means of interviews and focus groups. However, as little detail is provided on the results from the interviews and focus groups, only the findings from the questionnaire are reported here. The questionnaire included questions on learning style, fun and computational concepts. The results revealed statistically significant differences between the groups in two main areas. Firstly, students in the experimental group showed greater enthusiasm, commitment and motivation in their learning tasks when compared to those in the control group. This finding was supported by results obtained from the teacher data. Secondly, working with the programming technologies in the context of art education also resulted in the development of computational competencies (the use of loops, parallelisms and the possibility of creating music using technology) among the experimental group, an opportunity not afforded to the control group who learned without these technologies. The teachers identified several barriers to music/technology integration including the time spent on technology at the expense of musical expression and the need for specific teacher training for the technologies.

Lagerlöf et al. (2013) present findings on research on two 6-year-old children's experience of engaging with a computer-assisted music improvisation, MIROR Impro. This is a computer that, when connected to an instrument (keyboard), will play back a variant consistent with the player's style of playing on the instrument e.g. the speed or lightness of touch. It takes turns with the player creating a type of musical dialogue. The data from this research comes from a larger dataset and consists of a single case exploring the role of an adult. The research was conducted in a Swedish preschool during a forty-minute session attended by the two children and one of the researchers who had formerly been a preschool teacher at the school. During the session, the researcher assumes the role of the more-experienced participant. The session consisted of five key activities: an introduction, an exploration of the keyboard, transducing emotions through play, listening and imitating, and trying to design the computers response. Data is collected by means of a videorecording of the session. Results showed that the children were able to actively engage in music-making activities e.g. listening and imitating and creating. The researchers highlight two aspects of the session that they considered key to its success, the importance of adult guidance and the playful approach. A limitation of this study is the small number of participants, two, and the brevity of the intervention, one lesson. However, it was intended as a process study and the researchers now recommend further research be carried out in a wider range of settings.

Enablers in Performing Arts/Technology – Early Years/Primary	**Barriers in Performing Arts/Technology – Early Years/Primary**
• Accessibility of Technology • Creativity, collaboration and cooperation • Adopting a play-based approach • Guided interactions rather than spontaneous or child-led • Provision of stimulating material	• Time spent on technology at the expense of content on musical expression • The need for specific training for implementation teams in requisite technologies

Table 17 - Enablers and Barriers Identified in Performing Arts/Technology Literature in the Early Years and Primary Education Sectors

PERFORMING ARTS, VISUAL ARTS AND SCIENCE/MATHEMATICS

This section presents the research studies that explored the integration of both the performing arts and visual arts with science in early years/primary education. Four of the studies integrated the arts with science and one integrated the arts and mathematics. The studies integrated a variety of performing and visual art activities. The science focus in the studies spanned biology, chemistry, astronomy, physical science and environmental science. The number topics taught were from the measurement and number strand.

Performing Arts, Visual Arts and Science/Mathematics	
1.	Miranda, J., Maricato, R., Nova, J.V., Baptista, J.M., Monteiro, J.L., Freitas, N., Gonçalves, O., Vale, V. and Azul, A.M., 2016. Interdisciplinary and Participatory Research at Early Childhood to Biodiversity Education and Sustainable Development. In *Biodiversity and Education for Sustainable Development* (pp. 265-285). Springer, Cham.
2.	Hardiman, M.M., JohnBull, R.M., & Carran, D.T. (2017). *The Effects of Arts-Integrated Instruction on Students' Memory for Science Content: Results from a Randomized Control Trial Study*. Paper presented at the Annual meeting of the American Educational Research Association, San Antonio, Texas.
3.	Hardiman, M & Rinne, L. & Yarmolinskaya, J. (2014). The Effects of Arts Integration on Long-Term Retention of Academic Content. *Mind, Brain, and Education*, 8(3), 144-148.
4.	Graham, N.J., & Brouillette, L. (2016). Using Arts Integration to Make Science Learning Memorable in the Upper Elementary Grades: A Quasi-Experimental Study. *Journal for Learning through the Arts,* 12(1), 1-17.
5.	Garrett, R., Dawson, K., Meiners, J., & Wrench, A. (2018). Creative and Body-based Learning: Redesigning Pedagogies in Mathematics. *Journal for Learning through the Arts*, 14(1), 1-20.

Table 18 - Evaluation of Early Years and Primary STEAM Education Literature: Performing Arts, Visual Arts and Science/Mathematics

Miranda et al. (2016) report on ‘Exploring and Experiencing Mediterranean’, a collaborative project involving kindergarten teachers, artists, and researchers from science education, life sciences and humanities. The project was co-funded by COMPETE—Competitiveness Factors Operational Programme (FEDER) and National

Agency Ciência Viva, Lisbon, Portugal. The project sample was 53 children aged between ages 3-6 from four classes in a Portuguese kindergarten. The science learning was focussed on the biological processes associated with biodiversity in the Mediterranean. Several visual and performing art practices were employed throughout the nine-month project including: painting, mosaic construction, drama, role-playing and creative dance. Data collection methods included photos, videos, children's work and an interview/questionnaire to the children. The researchers noted that the integration of the arts with science gave the teachers greater insight into how the students constructed knowledge relating to biodiversity in the Mediterranean. They found that the science-art integration engaged the children expressively and promoted their curiosity about science concepts. Consequently, the need for inclusion of children's perspectives and interests in STEAM integration is emphasised. They also recommended use of the participatory research approach as it promoted dialogue between disciplines and led to mutual learning between children, researchers, kindergarten teachers, artists and researchers.

Two studies, Hardiman et al. (2014) and Hardiman et al. (2017) used randomised controlled trials to explore the impact of art integration on the long-term memory of science content. The Hardiman et al. (2014) research was conducted with 97 fifth grade students who attended an elementary school in the United States. The research was supported by the Joseph P. Drown Foundation. The researchers developed two science units on astronomy and ecology to be taught over a three-week period. For each unit they designed a version to be taught using traditional instruction methods (control) and another to be taught using instruction incorporating artistic activities (visual arts or performing arts) (experimental). The students were then randomly assigned to one of four groups and received one hour of science instruction per day over the three-week period. The students then completed another three-week period of instruction on the second unit with an alternative condition. For example, if they were taught the astronomy unit using traditional instruction methods in the first three-week period, they would be taught the ecology unit using instruction that incorporated artistic activities in the second three-week period. A multiple-choice assessment instrument was developed to collect data on the participants' learning and retention of the science content. Three versions of the assessment were developed, one version was used in the pre-test, one in the post-test and one in the delayed post-test. The results of the intervention showed there was no significant differences in initial learning, but arts integration resulted in significantly better retention. Furthermore, learners at the lowest levels of reading achievement demonstrated the greatest increases in retention. Learning by art-based means provides an alternative to text-based means. A limitation of this study was that all participants came from the same school.

Hardiman et al. (2017) aimed to build on the findings of the previous study by using a larger sample size and improving fidelity of implementation by scripting the lesson content for the teachers. The sample for this second study was comprised of 350 fifth graders from 16 classes across six different schools. Two additional science units, life science and chemistry were developed for inclusion in the study. This study employed the same method of assigning groups to treatment and control units as was described for Hardiman et al. 2017. The results of this study mirrored the findings of the earlier study.

Graham and Brouillette (2016) report on a quasi-experimental study that investigated the effect of STEAM lessons on the learning of physical science. The project was funded by an Improving Teacher Quality grant administered by the California Department of Education. Participants were randomly selected cohorts of students in grades 3-5 in California. There were two experimental groups and one control group. The first experimental group consisted of 893 students from five schools whose teachers had some professional development before the intervention. The second experimental group consisted of 1263 students from five schools whose teachers were co-teaching with educational artists. The students in the experimental groups were taught nine lessons using instruction incorporating visual and performing arts to review science concepts and vocabulary. The control group consisted of 5,683 students who followed the usual course curriculum. The scientific knowledge of all participants was assessed by standardised district wide tests. Both experimental groups showed improvements in their test scores. The scores of the experimental group who were taught by the teachers who had received professional development before the intervention were higher than the group whose teacher was co-teaching with the educational artists. The researchers concluded that students who participated in the STEAM lessons showed higher gains in the physical science assessments than those students who participated in STEM only lessons if general student scientific achievement is held constant. The researchers suggested some key enablers to successful STEAM integration were focus on a limited number of core ideas, focus on concepts that bridge disciplinary boundaries, learning is a developmental process that starts from a point of curiosity.

Garrett et al. (2018) report on the impact of a pilot study, that implemented an arts-integrated professional learning model, Creative Body-based Learning (CBL), on the teaching and learning of mathematics. The participants involved in the study were five teachers, teaching grades 1-7 at two schools in South Australia. The teachers were supported by two theatre/dance artists and two visual arts/drama artists. At the beginning of the project the teachers attended a two-day professional development workshop which explored CBL strategies that could be used to support mathematics teaching and learning. Following the workshop, the teachers and artists collaborated to develop mathematical lessons incorporating those CBL strategies.

At one school, the three teachers worked as a team with the two artists to create and teach lessons on the topics of measurement, fractions, and weight. At the other school, the two teachers worked individually with an artist to create and teach lessons on number, addition, subtraction, and fractions. The data collection methods were teacher semi-structured interviews, student perspectives, artefacts and evidence of key teaching moments.

The key research findings related to impacts on student learning were the value of CBL in promoting mathematical conversations; increased student engagement with and enjoyment of mathematics; students developed greater persistence in finding solutions to mathematical problems, particularly students who had previously struggled with mathematics; improvements in students' self-efficacy beliefs regarding their mathematical ability. Teachers also reported that using CBL afforded them greater opportunities to make connections between concepts, develop supportive classroom cultures and assess student learning in more effective ways. This study had several limitations including the use of self-reported data and a relatively small sample. This was acknowledged by the researchers who noted it was intended as a pilot study.

Enablers in Arts/Science/Mathematics – Early Years/Primary	**Barriers in Arts/Science/Mathematics – Early Years/Primary**

• Collaboration between specialists from the various sectors • Curricular materials to support teachers • Provision of professional development • Focus on a limited number of core ideas • Learning is a developmental process starting from curiosity • Focus on concepts that bridge disciplinary boundaries • Arts offered an alternative approach to access and demonstrate learning for those who struggle with reading • Participatory approach promotes dialogue between multiple disciplines and results in mutual learning • Inclusion of children's perspectives and interests	• Arts advocates uncomfortable that art integration can boost science achievement – looking for an equal emphasis on the intrinsic benefit of art experience • Variability in implementation fidelity • Narrowing of the curriculum • Extra time required to construct programmes • The need for specific expertise

Table 19 - Enablers and Barriers Identified in Both Art Disciplines/Science Literature in the Early Years and Primary Education Sectors

PERFORMING/VISUAL ARTS AND TWO OR MORE STEM DISCIPLINES

This section presents the research studies that explored the integration of the arts with two STEM disciplines in early years/primary education. These included a study integrating music and STEM, a study integrating music, technology and science, a study integrating visual arts and STEM and a study integrating the arts, technology and engineering.

Performing Arts and two or more STEM Disciplines

1.	Kaplan, M. (2017). Orchestrating a new approach to learning. *Phi Delta Kappan.* 98(7), pp. 23–28.
2.	Leonard, A.E., Dsouza, N., Babu, S.V., Daily, S.B; Jörg, S., Waddell, C., Parmar, D., Gundersen, K., Gestring, J., & Boggs, K. (2015). Embodying and Programming a Constellation of Multimodal Literacy Practices: Computational Thinking, Creative Movement, Biology, & Virtual Environment Interactions. *Journal of Language and Literacy Education*, 11(2), 64-93.
Visual Arts and two or more STEM Disciplines	
3.	Hunter-Doniger, T. (2021) Early Childhood STEAM Education: The Joy of Creativity, Autonomy, and Play. *Art Education*, 74(4), 22-27.
Visual Arts/Performing Arts and two or more STEM Disciplines	
4.	Malone, K. M., Tiarani, V., Irving. K. E., Kajfez, R., Lin, H., Giasi, T. and Edmiston, B. W. (2018). Engineering Design Challenges in Early Childhood Education: Effects on Student Cognition and Interest. *European Journal of STEM Education*, 3(3), 11.

Table 20 - Evaluation of Early Years and Primary STEAM Education Literature: Performing/Visual Arts and Two or more STEM Disciplines

Kaplan (2017) reports on an arts integration programme run by the Phoenix Orchestra in partnership with the region's public schools. The programme ‘Mind over Music’ aimed to bring together musicians and teachers to design and implement a STEAM curriculum. In the first three years of the partnership ‘Mind over Music’ lessons were held once a month. During that time the Symphony commissioned a quantitative evaluation of the programme. The quasi-experimental study found that the experimental group students were outperforming the control group students in state-mandated achievement tests and a customised assessments in both mathematics and science. At this point the symphony directors recognised the need for a more coherent evaluation of the programme. The programme was revamped in the 2015/2016 school year and expanded their participants to 45 teachers, 24 professional musicians and 1780 students. Four key principles were developed to guide the restructured programme: participation in the programme required the creation and delivery of a minimum of 10 lessons, mandatory participation in professional development workshops, classroom coaching by veteran STEM teachers and music educators, and the provision of an online repository of inquiry-based lesson plans. In year 4, teachers and their classes were randomly assigned to experimental and control groups. Teachers and students completed self-efficacy surveys at the beginning and the end of the year. Students also completed pre and post-tests in mathematics, science, language arts and music. The key finding highlighted by Kaplan (2017) was that the students in the experimental group made significantly greater gains in the self-efficacy survey, implying that students felt they learned and understood more STEM content when the music was integrated into the learning.

Whereas Kaplan (2017) explore the integration of music with the STEM subjects, Leonard et al. (2015), explore the integration of dance with the STEM subjects: technology and science. The participants in this study were 41 fifth-grade students from two classes in a public arts magnet school in the United States. The intervention consisted of eleven weeks of programming and choreographing sessions inspired by the parts of the cell (biology). Content from each of the three subject areas was explored during the learning sessions: science (structure and function of cells), technology (e.g., sequences, loops, conditionals and variables) and dance (theme and variation, repetition, unison, cannon, purposeful movement and flow). Looking Glass, a graphical programming environment which supports the creation of 3D animated stories, was chosen as the introductory programming platform. Data collection methods included pre and post computational thinking tests, video recordings of the sessions, student choreography notes and group discussions. SPSS was used in the analysis of the quantitative data collected from the pre and post-tests and qualitative discourse analysis was used in the analysis of the video recordings, notes and interview data. The paired sample t tests revealed significant gains in computational thinking scores between the pre-test and post-test. Engaging the parallel processes of choreographing a dance and programming a corresponding virtual characters' dance, afforded students the opportunity to engage in a variety of multimodal literacy practices including writing, speech, movement and computer programming.

In her case-study research Hunter-Doniger (2021) investigated how kindergarten students could discover STEAM subjects through the use of child-centred approaches such as play. The researcher used convenience sampling to select schools for inclusion in her study. Two forest kindergarten schools in Germany and two Dutch elementary schools with forest kindergarten components embedded in their curriculum were selected for inclusion in the study. The participants were aged between three and six years of age. Data collection methods included observations, field notes and journals. The researcher adopted a grounded theory approach to data analysis: beginning with a round of open coding, followed by a round of axial coding and a final round of selective coding. The key findings of this research study are as follows:

1. Play, autonomy and creativity are constant features of child-centred approaches. These features tended not to occur in isolation but rather were interwoven with each other and the content area.
2. The author compared the practices advocated by the child-centred approaches to the practices of real artists and scientists e.g., students are given autonomy to explore, discover and try new methods, concepts and theories.
3. She noted that STEAM pedagogies were prevalent in all of the schools, although they were not deliberately applied.

Malone et al. (2018) use a mixed-methods approach to evaluate the effect of a STEAM programme on students' engineering and technology understandings. This project was funded by the Improving Teacher Quality State Grants Program. The participants included over 200 students in preK-third grade attending five schools identified as low-achievers in science. The teachers involved in the programme included mathematics, science, dance, art and P.E. teachers. The teachers and specialists collaborated to create integrated STEAM units (i-STEAM units) by integrating elements of the instructional units from Engineering is Elementary (EiE), dramatic inquiry and visual art/dramatic art techniques. Each teacher taught at least one i-STEAM unit to their class. The students were given two assessments (engineering and technology) one week before and one week after the i-STEAM units were taught. The engineering assessment had been used and revised by Lapachelle and Cunningham (2014) and the technology assessment had previously been tested for validity and reliability with elementary students by Lachapelle et al. (2013). Data was also collected through teacher interviews. Analysis of the data revealed that implementation of the integrated STEAM units brought about significant improvement in the PreK-3 students' conceptual understandings of technology and engineering. This was reflected by a 36% increase in students' understandings of technology and 55% increase in their understandings of what engineers do (on average). The lack of a control group means the improvement cannot be definitively attributed to the intervention. The availability of curricular materials, such as the EiE units, is a support to projects integrating STEAM.

Enablers in Arts/Two or more STEM Disciplines – Early Years/Primary	Barriers in Arts/Two or more STEM Disciplines – Early Years/Primary
• Collaboration between specialists from the various sectors • The sharing of resources • Provision of professional development • Curricular materials to support teachers • Child-centred approaches - creativity, autonomy, play (CAP) • Learning process is exploratory and driven by student interest	• Negative beliefs of teachers • Ineffective evaluations • Inconsistent fidelity of implementation

Table 21 - Enablers and Barriers Identified in Arts/Two or more STEM Disciplines Literature in the Early Years and Primary Education Sectors

CONCLUSIONS AND SYNOPSIS OF KEY ENABLERS AND BARRIERS TO EFFECTIVE EARLY YEARS AND PRIMARY STEAM EDUCATION INTERVENTIONS

A review of the literature revealed that research on early years and primary STEAM education is happening across the world. The twenty-five studies included in this section of the literature review were conducted in five different continents: Africa, Asia, Australia, Europe, and North America. Research to date has predominantly focused on integration between one of the arts and a STEM discipline, most often science. Only four of the twenty-five studies integrated the arts with more than one STEM discipline. Research on the integration of arts with engineering was rare, with only one of this type of study found. The visual arts featured more prominently than the performing arts.

Sample sizes varied across the studies, with as few as two participants in some studies, and as many as 1000 in others. The United States accounted for many of the larger studies but there were also some larger studies in Europe. These larger studies tended to be funded by governmental agencies or public/private companies. There were several rigorous empirical studies that included randomisation, control groups and statistical analysis of data. Eleven of the twenty-five studies in this sector were studies of this nature. This was a particularly popular approach when the study included mathematics as the integrator. Five of the six studies that integrated mathematics employed a rigorous empirical design. In these studies, the arts tended to be subservient to the STEM discipline, with improvements in mathematical or scientific achievement prioritised in the findings. There were also some qualitative studies that were equitable in their treatment of the arts and STEM disciplines that provided insights into how discipline hierarchies might be avoided.

The enablers for effective STEAM integration were mirrored across different categories of studies. They included: input from and collaboration between specialists, objectives from each discipline, use of play-based approaches, focusing on concepts that bridge disciplinary boundaries, the trajectory of learning steered by student interests, humanising the disciplines using narratives, STEAM education arising from real-world problems, embracing young children's natural curiosity, professional development – particularly hands-on experiences, availability of supportive/adaptable curricula, experiencing success and persisting with new approaches.

The barriers to effective STEAM integration included: discipline hierarchies, lack of expertise, a narrow view of creativity, limited time apportioned, teachers' pedagogical approaches and interpretation of curricula, lack of support during implementation, availability of resources, low levels of self-efficacy of teachers, lack of buy-in from key stakeholders, lack of a formal curriculum, creativity taking time to nurture versus limited time.

Subsection B - Effective STEAM Interventions in Post-primary Education

This section initially included an index of 44 post-primary based articles, selected for consideration and potential inclusion in the final review. Following a careful reading of each of the 44 articles a further 18 were considered unsuitable. The remaining 26 studies were categorised by the art-based integration approach and STEM discipline, for comparative purposes. A table precedes each sub-section of studies, providing the title and reference of each study. Final analysis of the 26 remaining post-primary studies, yielded nine arts based and science studies, five arts and mathematics studies, eight arts and computer science/technology studies. Four studies which were not discipline specific but offered a broader cultural perspective on STEAM education were also selected. These 26 studies form the basis of the categorised findings and discussion in Section B.

PERFORMING ARTS AND SCIENCE

The majority of the studies including science as the STEM discipline presented findings from studies integrated with the dramatic or performing arts domains.

Performing Arts and Science	
1	Ong, K.J., Chou, Y.C., Yang, D.Y., and Lin, C. (2020). Creative Drama in Science education: The Effects on Situational Interest, Career Interest, and Science-Related Attitudes of Science Majors and Non-Science Majors. *Eurasia Journal of Mathematics, Science and Technology Education*, 16(4): 1831
2	Kolovou, M., and Kim, N (2020). Effects of implementing an integrative drama-inquiry learning model in a science classroom, *The Journal of Educational Research*, 113(3): 191-203.
3	Heuling, L.S., (2021). Promoting student interest in science: The impact of a science theatre project, *LUMAT Special Issue*, 9(2): 63–81.
4	Heras, M., Ruiz-Mallén, I., and Sandrine Gallois, S. (2020) Staging science with young people: bringing science closer to students through stand-up comedy, *International Journal of Science Education*, 42(12): 1968-1987.
5	Gershon, W. S., and Ben-Horin, O. (2014). Deepening inquiry: What processes of making music can teach us about creativity and ontology for inquiry-based science education. *International Journal of Education & the Arts*, 15(19): 1-38.
6	Burke, L., Wessels, A. and McAvella, A. (2018). Using theater and drama to expose and expand the epistemic insights of youth regarding the nature of science. *Research in Science Education*, *48*(6):1151-1169.
7	Adjapong, E.S. and Emdin, C. (2015). Rethinking Pedagogy in Urban Spaces: Implementing Hip-Hop Pedagogy in the Urban Science Classroom. *Journal of Urban Learning, Teaching, and Research*, 11: 66-77.
8	Queiruga-Dios, M.-Á., López-Iñesta, E., Diez-Ojeda, M., Sáiz-Manzanares, M.-C., Vázquez-Dorrío, J.-B. (2021). Implementation of a STEAM project in compulsory secondary education that creates connections with the environment. *Journal for the Study of Education and Development,* 44(4): 871-908.
9	Conradty, C., Sotiriou, S.A. and Bogner, F.X., (2020). How creativity in STEAM modules intervenes with self-efficacy and motivation. *Education Sciences*, *10*(3):70.

Table 22 - Evaluation of Post-primary STEAM Education Literature: Performing Arts and Science

Ong et al. (2020) investigate the effects of creative drama on interest, career interest, and science-related attitudes of science majors and non-science majors from five high schools in Malaysia. As the study involves participants from a range of post-primary schools, it is included in this section. However, it should be noted that the intervention took place in a designated university setting during the school holidays, to accommodate the diverse group of students from varied school contexts, and to be able to bring them together for the activities and learning phases of the project. Researchers investigated participants' perceptions toward creative drama during the project phases. Creative drama is a cultural pedagogy that focuses on improvisation and is process orientated rather than exhibition focused. Eighty-three, 16-18-year-old male and female students participated comprised of 50% science majors and the 50% non-science majors, categorised as those who take science at upper second level and those who do not. The creative drama activity was structured as a five-day event, held in the local university during school holidays. The composition of the research or teaching team was not clearly indicated. Formal science lessons, a science fiction movie clip workshop and presentation skills workshops, followed by group discussion built a range of content knowledge and skills among the student group, enabling them to dramatise science concepts and ideas over the week. Using pre and post-tests Likert scale surveys, results showed an increased interest in science, science careers and perceived enhanced creativity and problem-solving skills among the cohort. Challenges of the study include the small sample size and there was no control group, restricting the internal validity of the study. In addition, the study was conducted in the students' holidays outside the school which may have limited participation from certain demographic groups and may have led to a skewing of the sample of participants. The implications of the study were limited in that the conclusion cited that creative drama is an effective educational tool for STEAM educational interventions. However, the rationale for such effectiveness was that if students' interest in science is triggered earlier, they may choose science as their major during high school, eventually leading them to pursue science-related careers. More exploration of the facets of student learning developed via the intervention, which was well implemented and structured, were omitted. Enablers for student learning were evident in this study, for example, the data suggests that creative drama facilitates a student-centered learning approach. This resulted in an enhanced interest among students, because the creative drama approach fostered student autonomy, competence, and confidence, a noteworthy point.

This research by Kolovou and Kim (2020), presents the effects of implementing an integrative drama inquiry learning model in a science classroom in the US. The study uses a sequential mixed-methods procedure embedded in a quasi-experimental research design. The research sought to understand the effects of integrative drama inquiry on middle school students' achievement in a biology module. The Integrative Drama-Inquiry (IDI) learning serves to unify scientific and dramatic inquiries by bridging the diverse cultures of sciences and arts in schools. The study uses self-determination theory to elicit results. The researchers apply the three psychological needs that support learning, namely, competence, relatedness, and autonomy to elicit effectiveness of this STEAM intervention. Sixty-two ninth grade students with an experimental group (taught through IDI) and control group (traditional teaching), were taught 8 biology lessons over 4 weeks. Higher academic achievement and enhanced perceptions of competence within science concepts were reported in the IDI group. This was suggested to be connected to greater understanding and visualisation of abstract science concepts through simulation and role play. A cited enabler to the relative success of the research was that instructor had experience in implementing both drama-based and inquiry-based techniques, which may not be the case for many second level teachers. The authors acknowledge that inexperienced or untrained teachers might encounter challenges in terms of instructional techniques, assessment methods, and managing time effectively in implementing the IDI model.

Heuling's (2021) study is similar to Ong et al. (2020), in that the research focus was to promote student interest in science through a science-theatre project. The authors make an interesting distinction that art-informed teaching differs significantly from arts-based education in STEM. They believe arts informed teaching refers to approaches which can be characterised as *using* art-related creative processes and products as conduits for conventional subject education. Alternatively, art-based education in STEM (STEAM education), acknowledges the arts and artistic processes as having equal value in any intervention and learning. The authors present a solid argument integrating the arts into education promotes awareness that STEM disciplines are culturally dependent as a social practice. A small sample of twenty-five participants from a multi-ethnic background in a German public school, engaged in a non-randomised experimental study with no control group completing pre and post Likert scale surveys. The content focus of the project was on the science concept of galvanisation and the related science disciplines of physics and chemistry. The project was led by two artists, one artist-scientist, and the two classroom teachers of which one was the initiating science teacher. Results indicated that participants' interest in chemistry, physics, and galvanisation all increased. In addition, an interest in artistic practices was found, which was in keeping with equal integration and focus on the sciences and the arts elements of the intervention. The authors cite a significant barrier to their vison for the research. Despite intending the study to be a transdisciplinary STEAM education intervention, due to the contextual conditions of the formal education setting, the practical elements had to be set up as an *art-informed* science theatre project. Due to the norms and values of the formal systems of education, the authors admit that this educational project did not achieve an equality between students' scientific and artistic inquiry into galvanisation and the science related to it.

Heras et al. (2020), present findings from a European funded ‘Horizon 2020’ project aiming to bring science closer to students through stand-up comedy. This study explores the role that arts-based approaches play in science education. It aspires to dismantle potentially biased views and stereotypical frameworks of science, with a view to generating a more motivating science learning experience. This study was conducted in two secondary schools in Spain, one identified as working class and the other middle class. A total of 39, 16-17-year-old male and female students took part from across both schools. Students participated in a science education project that applied drama-based activities within a science inquiry process. Workshops during school time facilitated reflection, performing and dialogue on the nature of science. External science communicators and internal teachers from the school co-facilitated the workshops. Pre and post Likert surveys were administered to the experimental and a control group who took no part in the intervention. Qualitative observations, focus groups and reflective data were also collected and analysed. The quantitative data showed more positive students’ experiences of science learning but did not conclude that such significant differences were only due to the intervention. However, the qualitative insights provided evidence of a positive impact on students' attitudes towards science learning. Students reported an increased self-confidence and motivation in science learning and expressed an enthusiasm for more practical, and active science learning approaches. Findings also included new rapports and interactions with science, with greater creativity, inclusivity, and greater interaction among students. While student perceptions of science were positive pre-intervention there was a clear improvement in the students understanding of the nature of science, and enhanced enjoyment of science due to the students experiencing a new mode of learning via the performative approach. The authors suggest a need for early introduction of arts integrated programmes at primary level, as attitudes and interest to STEM disciplines can be defined early. Barriers cited for implementation of the intervention include a lack of time on the curriculum to develop performing skills and a need for greater collaboration and networking between schools and research institutions.

Gershon and Ben-Horin (2014) report findings from their research, which is different to other intervention type studies, but worthy of inclusion due to its unique focus. The authors present the arts as a means for conceptualising, understanding, and expressing science. They identify what science can learn from art rather than how a performing art can help with understanding about science. Few other studies took a focus from the perspective of the arts based educational element, nor used an ethnographic research approach. The authors discuss the relationships between music, sound, and inquiry-based science education. This was a four-year sonic ethnography, with the representation of data as sound. These sounds included lessons in science, students' conversations during science class, and interviews conducted with and by students about new science content they were being taught during science lessons. Students wrote songs about the science content of their choice, recorded audio reflections of their song writing processes. This data was inductively analysed to generate findings. They found that the processes of making music helped to foster an important moment of simultaneously being lost in process and completely present in that moment. The authors claim that inquiry-based science education and making music are both critical and creative activities, but they identify that musical inquiry tends to more immediately engage participants in deeply aesthetic and affective ways. They conclude that not only processes of artmaking, but also scientific and mathematical processes are aesthetic experiences in which the senses operate at their peak, and one is fully present in the lived moment. They identify new possibilities for music's relationship to inquiry-based science education. This study questions and ponders whether scientists might become more creative and open in their own inquiry, if they engage in processes of music making.

Burke et al. (2018) discuss how drama can be used to explore epistemologies of science and the nature of science. The study was conducted with two groups of 14-18-year-old secondary school students from contextually different settings in Canada. One site was a private university preparatory school (n=35) and the other, an after-school community group in a low-income neighborhood (n=20). Using a combination of instruments and contemporary methodologies the authors identify students' perspectives on the nature of science. Students silently dramatised the characters of science and the science student. Students also generated the opening scenes of a science-themed play, based around science issues of their choice. The students' personification of science activities revealed the kinds of relationships students had with science and their perceptions on the authority of science in the education system and beyond. Despite similarities in the perspectives shared by the two groups when using the more traditional nature of science testing format, the drama activities uncovered differences in how the two cohorts mobilised their understandings about science. The preparatory school positioned science as a powerful authority and a valuable career option, while the after-school community group demonstrated the complexity and messiness of the field of science but did not see it as a career option. This study is valuable as it highlights critical perspectives around how an intervention can be culturally relevant and how social class intersects with career aspiration in the field of STEM. The arts-based element was powerful in unearthing differences in attitude and perspectives on the nature of science among a diverse cohort. Performing arts as an arts-based intervention, may act as an enabler to generate science capital for marginalised groups.

This research by Adjapong and Emdin (2015), is rooted in a socio-cultural framework and provides insight on ways Hip-Hop can be incorporated into the art and science of teaching. The primary site of this study is a sixth grade science classroom in a public middle school, located in the northeast region of the United States. The primary data collection sources for this mixed methods study were student focus groups, video vignettes and a Likert scale questionnaire. Hip hop culturally relevant pedagogical approaches namely, 'call and response' and 'co-teaching' were used in science classes over a limited period. The researchers claim that 'Hip-Hop' pedagogical practices supported students' science content knowledge, connected science content to students' lives, and supported student voice and agency. The evidence within the results of this study illustrated that students memorised and understood science content better following their exposure to both the call-and-response and co-teaching approach. This was because it allowed a shift from rote learning to active engagement, using culturally relevant teaching. In addition, students were able to communicate scientific content to their peers more efficiently than their teacher, due to their membership of the same community and shared cultural capital.

Queiruga-Dios et al. (2021) report the results of a STEAM project with secondary school students using project-based learning, and by integrating science and art-based education. The sample were 26 male and female teens from one school in

Northern Spain, all aged 15-16 years. Extensive use of mixed methods included observation of student work, assessment rubrics, Likert scales, pre and post surveys and interviews. The STEAM project focused on astrobiology with the main idea revolving around space exploration and the search for life. Students were tasked with creating a storyboard followed by a two-minute science fiction animated movie over a period of weeks, to represent their learning and creative engagement. Extensive support from inside and outside the school, via local institutions, researchers, technology centers, and museums, enabled a dual approach to scaffolding student learning. A group of teachers including science, art and literature specialists mentored the intervention and this was an important enabler, as the creative and scientific processes could be integrated more effectively with the creation of a STEAM teacher team. Opportunities that emerged from this comprehensive approach to learning included the development of significant relational connections among students, parents, teachers, and outside agencies. A social constructivist approach to the research facilitated effective learning among the participants. The authors highlight that the students became educational agents during the research process, enabled by the adaptation of the curricular structure commonly found in schools to a more flexible one. This allowed teachers to generate extensive connections among stakeholders within and beyond the research group, which enhanced the limited context in which teaching can often occur. Descriptive statistics on survey data indicated a statistically significant increase in the performance and interest in science among the participants, as well as enhanced teamwork and other skills. No significant differences were found with respect to gender.

Conradty et al. (2020) comprise a team of researchers working on ‘Creations’, a large-scale project funded by the European Union, where 16 partners from ten European countries developed creative approaches based on art for an engaging science classroom. Pre and post intervention data from a sample of 928 students (aged 9–18 years), were analysed. A series of lessons combining science/mathematics and art were delivered. Limited detail was provided as to what the ‘art’ part of the intervention entailed. The focus of this study was to motivate students with STEAM to pursue a science career, like other funded projects as cited earlier. It was claimed that the art element of the intervention was being used to instill creativity into the lessons.

Due to this prioritisation of STEM over the Arts, it could be argued this is not an authentic STEAM intervention, despite the size of the study and its status as a European collaborative project. There are limitations with this study in that the definition of creativity and its measurement is challenging. Some broad summative points are presented when the authors conclude that teachers can enhance motivation through improved individual self-efficacy, by developing STEM into STEAM, with the focus on students' creativity. This study highlights those large experimental studies often result in several publications each exploring extracted singular elements of the study, which can lead to a lack of clarity about what the intervention involved for student participants. This makes evaluation of the effectiveness of the STEAM intervention difficult.

Enablers in Arts/Science – Post-primary	Barriers in Arts/Science – Post-primary
• Multidisciplinary Team with arts and STEM staff involved in intervention. • Creating connections with a variety of stakeholders within and outside the school, e.g., museums, researchers, and parents. • Adopting a social constructivist approach for peer support. • Empowering student participants to become educational agents. • Flexibility and adaptation of the formal curricular structures. • Utilising student-centered approaches and less traditional STEM teaching methods. • Practitioners with the ability to implement science and arts-based approaches leading the project.	• Lack of time and inadequate coordination of project with a large, varied team. • Inadequate availability of resources to complete the project. • A lack of leadership support. • A lack of meaningful integration of the arts. • An over focus on the STEM learning at the expense of the arts-based education. • An ulterior motive within the research, to generate workers for the STEM pipeline instead of focusing on knowledge, skills, and attitudinal learning. • Poor teacher understanding of STEAM education. • Practitioner resistance to change. • Lack of professional development among facilitating teachers in either arts or STEM based disciplines • Due to the norms and values of the formal systems of education, arts-based education is difficult to achieve and can become arts informed instead.

Table 23 - Enablers and Barriers Identified in Arts-Based and Science Literature at Post-primary

PERFORMING/MUSICAL ARTS AND MATHEMATICS

There was a dearth of effective examples of arts-based and mathematics integration in the selected literature. Music was integrated in most of the studies involving mathematics, with a few exploring creativities, through design based artistic approaches. These articles offer the greatest rigour and innovation but are not without significant limitations in some cases, as the synopsis details.

Performing/Musical Arts and Mathematics	
1	Walker, E., Tabone, C. & Weltsek, G. (2011) When Achievement Data Meet Drama and Arts Integration. *Language Arts*, 88(5): 365-372.
2	Torralba, J. (2019) A mixed-methods approach to investigating proportional reasoning understanding in maker-based integrative steam projects. *Fablearn 2019 8th Annual Conference on Maker Education*, Teachers College, Columbia University, New York; March 10th, 2019.
3	Thuneberg, H. M., Salmi, H. S., Bogner, F. X. (2018). How creativity, autonomy and visual reasoning contribute to cognitive learning in a STEAM hands-on inquiry-based math module. *Thinking Skills and Creativity*, 29: 153-160.
4	Snyder, L., Klos, P. & Grey-Hawkins, L. (2014). Transforming Teaching through Arts Integration: AI Implementation Results: Middle School Reform through Effective Arts Integration Professional Development. *Journal for Learning through the Arts,* 10(1): 1-26.
5	Kukreti., A., Jackson, H., Steimle, J., and G. L. Ogden, (2014). Math projects integrate engineering design & artistic creativity. *IEEE Integrated STEM Education Conference*, 1-5.

Table 24 - Evaluation of Post-primary STEAM Education literature: Performing/Musical Arts and Mathematics

Walker et al. (2011) present research findings from a large-scale study that encompasses the integration of theatre arts and drama into social studies, language, and mathematics in post-primary schools in the US. This study is included in this art and mathematics section due to the authors' claims that the effects of the intervention impacted mathematics performance, despite it not being clear how the arts were integrated with mathematics during the project. This may be due to omissions in the Walker et al.'s (2011) methodological reporting, or indeed a misunderstanding or misinterpretation in the review of the study, of how integration with mathematics did occur, during the intervention. What this study does offer is an example of a large-scale study that encompasses much of what Sloane (NSF, 2013) says about quantitative rigour. That said, we note several criticisms in terms of the authors' presentation of how or indeed if arts were meaningfully integrated with mathematics. The study design does include numerous levels of randomisation. Four experimental schools' classes were randomly assigned for inclusion in the integrated arts project, and four control schools' classes did not engage in the arts-based intervention and served as comparison schools. Twenty-eight teachers were evenly and randomly assigned to the experiment or control groups. 540 students participated in the experimental group and 480 in the control group. 80% of students were from disadvantaged backgrounds. Forty arts integrated lessons were designed using core novels used in the district. The artists and teachers participating in the study worked toward integration of the national theater arts standards in each of the lessons and found common and natural points of intersection between both dramatic arts and literary disciplines. Researchers used data including standardised assessment results in mathematics and language arts, available through the school districts and school data offices. Student engagement was measured using days absent from school as the key parameter. Results following statistical analysis showed sustained improvements in achievement in language and mathematics. 56% of students in the theater arts classrooms passed the state assessment in language arts, with a pass rate of 43% for students in the control classrooms. In mathematics, 47% in the integrated classrooms passed the state assessments, with 39% of students achieving a pass in the control classrooms. The authors conclude that a contribution of arts impacts on student learning and attendance. A strong association was found between their students' arts-in-education interventions and improved academic achievement. This was especially evident for students from low-socioeconomic backgrounds. However, as the integration seemed to be primarily between drama and language arts, with no clearly articulated insights into whether there was a specific arts-based intervention in mathematics lessons, or not. Therefore, although the results show statistical significance in some mathematics results, there is limited discussion or inference into how these improvements occurred. This is a potentially significant weakness in terms of the reliability of this study and it is arguable that other uncontrolled variables may have impacted the pass rate improvements in mathematics. This excerpt highlights that STEAM education research that may be rigorous in terms of design and methodology must be judicious in how it manages claims based on indirect results or extrapolation of data.

Torralba (2019) explores the 'Maker Movement' and investigates mathematics based proportional reasoning learning through maker-based curricula. Maker spaces encourage learners to create and explore without the fear of failure and using a variety of low and high-tech tools that are in maker spaces, learners can engage with a set of activities that can be designed with a specific goal in mind. This mixed methods study examines the impact of a maker-based programme in a formal school setting. The study is bound as a case study conducted in one school involving 30 thirteen-year-old students. Arts and mathematics teachers were co-facilitating the research. This article focuses on the ‘Geometric Moving Art’ project, one of 6 arts-based modules, which lasted about six weeks. The goal of this project was for small groups of students to design, build, and present a geometric moving art piece, using the resources available in the school-based modified makerspace. Pre and post testing changes in performance were based (like the last study) on mathematics state standards with qualitative analysis of students’ final products also used. One third of students scored lower on post-tests, one third higher and one third showed no change. The authors conclude that standardised tests should not have been used as the instrument to assess learning outcomes generated through STEAM activities, given the constructionist focus of the course. The individual scores in the groups did show a high proficiency level of understanding of proportional reasoning following the intervention. The final products also illustrated significant mathematical geometric understanding, despite the test scores. The need for teachers to have adequate training in generating and teaching STEAM projects is highlighted. Anecdotally, the autonomy that STEAM projects allowed the teachers aided the development of 21st century skills among the students, but this was not formally measured.

Thuneberg et al. (2018) report on a Horizon 2020 project entitled ‘Creations’, that investigates how creativity, autonomy and visual reasoning contribute to cognitive learning in a STEAM hands-on inquiry-based mathematics module. Participants included 392 male and female 12/13-year-old students, from eleven schools in Helsinki. A three-lesson module was developed that explored geometric mathematical phenomena. Participants were provided with a commercially available hands-on construction kit. Participants were engaged in building original and individual geometrical structures using varied resources which facilitated high levels of creativity and autonomy. Tutors from the teaching staff supervised the construction process and facilitated rather than intervening with the students unless asked for help. A pre- and post-test research design facilitated the monitoring of the students’ cognitive knowledge and the variables of relative autonomy, visual reasoning, formal operations as well as creativity. Results following statistical analysis showed that the creation of geometrical structures as an intervention was effective in generating newly acquired cognitive knowledge, although the effects are small. The analysis of the pre and post-tests showed that this new knowledge resulted from the 'external triggers,' such as the processes of creativity, in particular act and flow, visual reasoning and relative autonomy. The girls mean knowledge caught up on the boys pre-scores (which were initially higher), following the intervention, indicating a bridging of gender differences.

Snyder et al. (2014), present a whole school approach to arts integrated learning across the curriculum including in all mathematics lessons via a specific 'Math Arts Integration Project', integrating visual arts to create 2D geometric art pieces. Qualitative and quantitative data were collected and assessed using a quasi-experimental design from the treatment and comparison schools. Significant professional development was offered to teachers across all content areas, including an intensive weeklong workshop for teachers with artists followed by a two-week teaching lab with students. Evidence is presented of increases in the region of 20% in student achievement on state-wide assessments with improvements across all cohorts in mathematics over a four-year period. The authors also conclude that implementing an arts integration model positively correlates with a 77% decline in discipline referrals, and overall positive change in school climate based on teacher, staff, student, and parent perception. However, the authors concur that while it is not possible to solely attribute the school's improvement to the arts integration intervention, the evaluation results do suggest that the comprehensive nature of the model implemented was effective. Success was also enabled and impacted by significant professional development, teacher collaborative planning and collegial teaching as well as access to an arts integration support team and collaboration with artist in residence. The full support of school administration was also cited as influential for the success of the intervention. This project involved massive involvement of partners and a considerable time commitment, which was challenging at times. Teachers reported significant pressure from management to work hard and this was a barrier to future engagement, due to resulting workplace stress. This model has been embraced by other schools due to its success.

Kukreti et al. (2014) co-researched a project funded by the National Science Foundation, with the aim to empower secondary mathematics teachers to integrate fine arts, the engineering design process and challenge-based learning into their teaching. Challenge-based learning is a multi-disciplinary educational approach that supports students to use varied content knowledge creatively to solve real world problems. A detailed account of one of the projects is provided. It involved the redesign and prototyping of a cereal box to reduce impact on the environment while holding the same volume of products. Results in mathematics improved following analysis of pre- and post- test data, as did motivation and application in class. While the engineering, mathematics and language elements were well developed in this project, the arts-based education emerged as less integral to the overall process. For example, the graphics on the newly designed cereal box constituted the ‘art piece.’ The authors did acknowledge that involving the art teacher the next time the module was delivered would benefit the development of the art processes. This lack of artist input throughout the project could be viewed as a limitation to the authenticity of this STEAM project. While this project yielded some success, it is typical of many of the STEAM research reported, where there is a dearth of meaningful arts education and where the focus is on the STEM discipline.

Enablers in Arts/Mathematics – Post-primary	**Barriers in Arts/Mathematics – Post-primary**
• Teachers not intervening facilitated greater autonomy and creativity among students. • Adopting a social constructivist approach. • Multidisciplinary Team with arts and STEM staff involved in intervention. • The full support of school administration	• Insufficient time and coordination of large projects with a varied team. • Claiming positive impacts on a STEM discipline without intervening directly in that area. • Putting too much emphasis on an applied benefit of an intervention. • Using instruments not designed for the intervention e.g., standardised tests. • Pressure and a requirement from management for staff to engage in a whole school approach to STEAM.

Table 25 - Enablers and Barriers Identified in Arts Based and Mathematics Literature at Post-primary

MUSICAL ARTS AND COMPUTER SCIENCE/TECHNOLOGY

The musical arts and dance-based arts approaches were integrated most often with computer science technologies. One group of studies evaluate 'Earsketch' with four publications arising from the same technology. Other research beyond Earsketch is subsequently discussed.

Musical Arts and Computer Science (Technology) - Earsketch	
1	McKlin, T., Magerko, B., Lee, T., Wanzer, D., Edwards, D., Freeman, J. (2018). Authenticity and Personal Creativity: How EarSketch Affects Student Persistence. *Proceedings of the 49th ACM Technical Symposium on Computer Science Education.* SIGCSE'18, February 21-24, Baltimore
2	Engelman, S., Magerko, B., McKlin, T., Miller, M., Edwards, D. and Freeman, J. (2017). Creativity in authentic STEAM education with EarSketch. In *Proceedings of the 2017 ACM SIGCSE Technical Symposium on Computer Science Education* (183-188).
3	Freeman, J., Magerko, B., Edwards, D., Miller, M., Moore, R. and Xambó, A., (2016). Using earsketch to broaden participation in computing and music. *13th sound and music computing conference*, Hamburg, Germany, 31 August-3 September
4	Magerko, B., Freeman, J., Mcklin, T., Reilly, M., Livingston, E., Mccoid, S., & Crews-Brown, A. (2016). EarSketch: A STEAM-Based Approach for Underrepresented Populations in High School Computer Science Education. *ACM Transactions on Computing Education (TOCE), 16*(4): 14.

Table 26 - Evaluation of Post-primary STEAM Education Literature: Musical Arts and Computer Science/Technology

EARSKETCH

Studies by McKlin et al. (2018), Engleman et al. (2017), Freeman et al. (2016) and Magerko et al. (2016) all evaluate interventions involving 'EarSketch'. While it is of interest that all the computer science STEAM interventions integrated with music as the arts-based educational discipline, several studies included in this final selection present research on a specific intervention called 'EarSketch'. Research on EarSketch, as a STEM intervention, is funded by the National Science Foundation and the https://earsketch.gatech.edu website provides useful insights into the intervention. While each study had a slightly different focus, for publication purposes, the

EarSketch STEAM concept was integral to all four studies. EarSketch is described as "a collaborative and authentic learning tool" that introduces post-primary students to programming, through the process of remixing music (Engleman et al. 2017, p 183). EarSketch aims to broaden participation in computing and computer science by creating a learning environment that has real world application and personal relevance for students in both computational and musical domains.

The EarSketch learning environment consists of digital audio stations operating within a web-based programming domain. Students are enabled to write Python or JavaScript code. This allows students to create music in popular genres using associated algorithms. EarSketch students write the code with the aim of creatively manipulating musical samples. The process also enables them to learn computing fundamentals such as lists, loops and other key functions. The EarSketch curriculum is closely aligned with computer science principles.

The McKlin et al. (2018) study examines how EarSketch affects creativity and student persistence. Researchers conducted a quasi-experimental study with a path analysis, using data collected from 205 students from five high school computer science programming classes. Results suggest that perceived authenticity and relevance of learning beyond the classroom significantly impacts positive learning dispositions in computing and music. In addition, authors claim that personal creativity, collaboration and developing an identity based on belonging to a learning space significantly enhances students' intention to persist with problem solving.

Freeman et al. (2016) present a similar paper that details the design of the EarSketch curriculum and learning environment cited above, including its integration across varied contexts to date. It also summarises key findings from the EarSketch pilot study. Use of a variety of research methods, including questionnaires, content assessments, observations, interviews, and focus groups, the pilot results suggest that EarSketch has significant potential to engage female students, in computing and music.

Magerko et al. (2016) detail how EarSketch was used in both formal and informal settings, to assess how varying the learning environment and context might impact student learning. The intervention yielded positive improvements in student content knowledge and positive attitudes toward computing. Importantly, as cited in the last study, this was especially evident in female populations that are currently underrepresented in computing fields. One key enabler identified across these studies was the importance of providing teachers with an online teacher curriculum, which complemented the student curriculum. This supported teachers with learning how to implement and understand the processes of the EarSketch programme.

OTHER MUSICAL ARTS AND COMPUTER SCIENCE (TECHNOLOGY) INTERVENTIONS

Beyond the EarSketch research there were a number of other varied and interesting studies integrating arts with computer science.

Musical/Visual Arts and Computer Science (Technology)	
1	Lindberg L., Fields DA., and Kafai YB. (2020). STEAM Maker Education: Conceal/Reveal of Personal, Artistic and Computational Dimensions in High School Student Projects. *Frontiers in Education*. 5(51): 22-41.
2	Leonard, A., Daily, S., Jörg, S., and Babu, S. (2021). Coding moves: Design and research of teaching computational thinking through dance choreography and virtual interactions, *Journal of Research on Technology in Education*, 53(2):159-177.
3	Devaney, K., (2019). 'Waiting for the wow factor': Perspectives on computer technology in classroom composing. *Journal of Music, Technology & Education*, *12*(2): 121-139.
4	Champion, D.N., Tucker-Raymond, E., Millner, A., Gravel, B., Wright, C.G., Likely, R., Allen-Handy, A. and Dandridge, T.M. (2020). (Designing for) learning computational STEM and arts integration in culturally sustaining learning ecologies. *Information and Learning Sciences*, *121*(9-10): 785-804

Table 27 - Other Musical Arts and Computer Science (Technology) interventions

Lindberg et al. (2020) report on a STEAM project that explores computer science with exceptional attention to the arts integration, within the project. The authors designed and implemented the intervention as a 13-week curricular intervention integrating an e-textile maker-based project with complex computer science content and elements of the visual arts were also included. Students engaged in creating or representing a community meaningful to themselves, using e-textiles as a medium, over time. The art intent behind the work was evident in reading the methodology, with students engaging in conscious, on-going reflections on their designs throughout the process and designing for an audience, from the outset. Ethnographic data collection methods including observational field notes and pre and post interviews were used. The two researchers were experienced in e-textiles and arts and coordinated the project. Four detailed and richly descriptive ethnographic case studies of students as maker-artists were presented as findings. In analysing the students' artifacts as well as their design processes, the authors identify three distinct artistic elements of importance. These elements supported students' creativity and design skills. These elements include articulation of the intent behind the work, conscious, on-going reflection on their design, and the value of designing for an audience. These elements scaffolded students to create computational art that reflected their individual experience in the wider world. This positioned their work as personally relevant but also as contributing to a larger community. Findings from the project included evidence of meaningful engagement with both STEM and art learning and the promotion of student reflexivity. In addition, students learned many sophisticated computing concepts, but the experiential elements of the study were centralised. Of particular interest in this study is the authors' argument for varied pedagogies in STEAM education. They claim that usually maker projects in STEM learning are focused on learning to use a specific tool to develop a particular skill, and the skill is subsequently evidenced by the product that is produced. They argue that this project was effective and enabled the productive teaching of students to competently use technology while also engaging in personal reflection and personal expression, which is a modified and novel approach to 'maker' education.

Leonard et al. (2021) present research funded by the National Science Foundation, examining the teaching of computational thinking through dance choreography and virtual interactions. Researchers employed a design-based research approach, a paradigm considered effective for studying learning in context. This is a mixed methods study of five educational contexts where the creation of a dance performance was actualised in a virtual environment. The intervention took place in formal classes and also in an after-school programme and summer camp. Students (n=170) volunteered to join the project based on an interest in computing and/or dance. Pre and post computational thinking tests were used to assess changes resulting from the intervention. In addition, pre and post biographical surveys were collected to assess dance expertise of individual students. Interviews were also conducted to generate attitudinal data on the project. Results following the intervention found enhanced computational thinking and evidence emerged of a perceptional shift among students away from biased representations of who computer scientists are. The aim of the project was to develop culturally relevant pedagogies with a view to expanding educational opportunities for a diverse group of students. Computational thinking test scores increased as did inclusive learning engagement and interest in computer science. Researchers acknowledge the small sample size in some of the educational settings, and the need to explore the approach with a larger audience to gather further data on the intervention.

Devaney (2019) provides the only UK based research, which investigates perspectives on computer technology in music classrooms, with a focus on the composing strand of the curriculum. This article problematises how and why computer technology is being used for composing in upper secondary school music classrooms using an interpretivist approach. It is not a STEAM intervention but is useful as it examines the type of integration between technology and music being implemented in schools and evaluates the effectiveness of these practices. Data were collected through a mixed-methods approach of five case-study schools using classroom observation, student focus groups, interviews, and a survey of 112 classroom music teachers. 27 students across the five schools participated. Findings outline both positive and negative aspects of using computer technology to compose, such as how it was often perceived as a shortcut, simply used to speed up the composing process. The study finds that using computer software for composing can also encourage a linear approach, rather than the more authentic, complex, and messy process of composing. The students felt that the unrealistic digital sounds from the computer software were a demotivating factor for students' creativity. A barrier to effective STEAM education is evident in this study, whereby the technology was being used to manage a time-pressured curriculum, and where the technology is not integrated with a view to enhancing learning or learner experience, it is used to expedite a process.

A study by Champion et al. (2020) investigates computational STEM learning, using learning ecologies, such as hip-hop music, practices, and culture. It evaluates culturally sustaining learning experiences as resources for enhanced youth participation in STEM education. There were 29 participants, aged 6–17 engaged as participants in this study. Twenty-eight identified as African American and/or Black, and all attended a four-week hip-hop computational summer camp. The focus of the camp was to explore the ways in which curriculum designers might arrange relationships between ideas, tools, materials, space, and people. The intervention focuses on the integration of hip-hop music production and relevant computational practices. The project team was interdisciplinary, comprised of scientists, a computer scientist, engineering educators, and members of the urban education community. Data collection methods included observation and interview. Participants learned to programme computational art through programming languages (e.g., Scratch) and to programme music through software designed for music production (e.g., Apple GarageBand programming). Activities were designed to encourage self-expression. Students were challenged to develop their own hip-hop computational creations, using materials available in the space. Students learned about building up and breaking down codes and engaged with the patterns as algorithms through music and making dance. The researchers found that cultural ecologies can support STEM engagement in marginalised groups. They highlight that STEM disciplines are often considered 'culture-free' objective domains, when they are often embedded in gendered, classed and raced value systems. These findings illustrate how the girls' computational decisions were guided by hip-hop rules of creativity and interactivity. They conclude that hip-hop can be an effective culturally sustaining pedagogy and a contributor to learning in computational STEM.

ENABLERS AND BARRIERS - ARTS INTEGRATION WITH COMPUTER SCIENCE

In summary and in addition to many of the enablers and barriers cited following review of the studies pertaining to science and mathematics, the literature related to computer science emphasises the value of student reflection and expression in the learning process, as a key enabler of effective STEAM learning. Importantly, an additional barrier to effective STEAM education is the use of computer technology to speed up a learning process, rather than contribute in any meaningful way to the learning.

COMPLEMENTARY POST-PRIMARY STEAM LITERATURE (NOT DISCIPLINE SPECIFIC)

A small number of selected studies did not align with mathematics, science or computer science, the prevalent STEM disciplines integrated with arts-based education, in literature**.** This research is briefly synopsised here for reference, as it contributes to the general post-primary landscape of practice in STEAM education.

Complementary Post-Primary STEAM Literature	
1	Hunter-Doniger, T. and Sydow, L., (2016). A journey from STEM to STEAM: A middle school case study. *The Clearing House: A Journal of Educational Strategies, Issues and Ideas*, *89*(45): 159-166.
2	Grzybowski, D.M., and Dixon, K. (2016). RTP Design as the Practice of Probability: Engaging Adolescent Girls in Art-Infused Engineering, *ASEE annual conference and exposition*, New Orleans, June 29th, 2016.
3	Kang, N.-H. (2019). A review of the effect of integrated STEM or STEAM (science, technology, engineering, arts, and mathematics) education in South Korea. *Asia-Pacific Science Education*, 5(1): 1-22.
4	Ng, W., and Fergusson, J. (2020). Engaging High School Girls in Interdisciplinary STEAM. *Science education international,* 31: 283-294.

Table 28 - Complementary Post-primary STEAM Education Literature (not discipline specific)

Hunter-Doniger and Sydow (2016) discuss one school's journey from STEM to STEAM. This research article provides data from the first year of a longitudinal study of a middle school in South Carolina. Site-Second level school with 770 students. Due to falling ratings in STEM, a STEAM focus was developed. The core STEAM leadership team consisted of seven faculty members, including four arts educators, two non-arts teachers, and an administrator. Methods for data collection included surveys, observation, interviews and field notes. The central focus of the STEM to STEAM introductory year was to begin to infuse the arts successfully into every classroom. The concern most faculty articulated, at 62 percent of respondents, was a lack of time to work with both the arts and academic subjects. In addition, disruptive behaviour and how to assess the arts were cited as challenges and significant resistance from teacher ensued. Enforcing a STEAM approach may damage self-efficacy and have a negative impact on teaching and learning if practitioners are not committed and have a belief in the STEAM curriculum. Importantly, trying to do too much too soon from a whole school perspective is not wise.

Grzybowski and Dixon (2016) present data from a mixed methods study that examines how adolescent girls connect engineering and the visual arts as a field of study. The researchers argue that when the two disciplinary areas are integrated, girls can develop a deepened understanding of the nature of engineering and the nature of art. 27 male and female middle school students from one STEM centered urban school took part in the research. Over a year, students attended after school classes as a treatment (engineering only club) and control group (engineering *infused* art club). Participants were simply offered an opportunity to join the science or the art club. The engineering aspect to the art club was not mentioned to participants in order to gather unprejudiced data. An interdisciplinary team was gathered comprised of education researchers, graduate engineering students, art and art education graduate students and art specialists. This team collaborated in the planning and implementation of all engineering/art club activities. As well as data from the quantitative quasi-experimental design, namely an 'attitudes towards science' inventory survey, qualitative data collection included focus groups, semi-structured interviews and participant observation. The article provides preliminary analysis of findings as the study was ongoing. The science self-concept scores across both genders in the art infused engineering club show no difference. In the art infused engineering club, there were improvements in self-concept in science and mathematics and decreases in anxiety in both. However, there was high attrition out of the art infused engineering club. Many girls left the art club, citing disappointment that the art club did not have enough art and felt too science orientated, and there was too much direct instruction and not enough creative freedom. This is an interesting outcome as it highlights the tendency for educators to focus on the STEM discipline and in doing so marginalise the art practices.

Kang (2019) published a STEAM education review paper, and this is not an intervention study. Nonetheless, it details and reiterates several of the enablers and barriers to effective STEAM interventions collated from the researched review at post-primary level, in preceding sections. In summary, the review paper highlights that professional development has a significant role in enhancing teacher confidence as STEAM educators. The review also calls for more research focused specifically on connections between teacher perceptions of STEAM, and their practice while teaching students. The review finds that interventions and learning experiences within STEAM education are effective in both the cognitive and the affective/relational learning domains of students. This literature review failed to identify significant or dominant mediating factors for successful STEAM education interventions and state that further studies are required to assess contextual and other variables that may play a functional role in such student learning.

Ng and Fergusson (2020) provide a varied contextual offering in their Australian research study, engaging high school girls in interdisciplinary STEAM project called the STEAMpunk initiative in a large study of 14 schools. In Australia, males make up 84% of the total population with STEM qualifications and few women enroll in STEM programmes or working in STEM careers or industries. The STEAMpunk girls programme uses project-learning and design thinking strategies to generate confidence and interest in STEM. A professional learning programme was provided for participating teachers, which modeled the processes that the teachers would follow with their students. The process focused on problem-based learning using the following model:

1. *Hook event* – Introduction of the programme to generate interest and enthusiasm among students
2. *Empathise* – Students conducted research to understand user needs
3. *Define* – Students defined what the problem was
4. *Ideate* – Students used their empathy work to generate a range of creative solutions quickly
5. *Prototype* – Students modelled and built prototypes of best ideas
6. *Test* – Students presented their prototypes to each other and got feedback
7. *Showcase* – Students pitched their project to classmates, teachers, family, community members etc.

Using a mixed method approach, with pre and post testing of female only student participants, the findings indicated that students were positive about their experience of the STEAM project, with significant increases in confidence and motivation among the girls at the end of the programme. The findings suggest a need for girls to engage more in STEM projects in an all-girls environment with the support of STEM role models or STEM student mentors to support them. The authors acknowledge that this STEAM intervention would have potentially benefitted from using an interdisciplinary STEAM approach to motivate and engage girls in STEM education, especially in the longer term.

CONCLUSIONS AND SYNOPSIS OF KEY ENABLERS AND BARRIERS TO EFFECTIVE STEAM INTERVENTIONS AT POST-PRIMARY LEVEL

The literature selected following the systematic search and review highlights a few key factors to aid understanding of the STEAM landscape at post-primary level. Firstly, there are few studies that would be categorized as highly rigorous empirical studies, with many empirical studies indicating a lack of randomization, control groups and limited statistical evaluation of data. This is understandable given that STEAM education is new and there is still a level of ambiguity among practitioners and indeed researchers as to what effective STEAM education entails. What is discussed in the preceding section is the most relevant and effective studies available at this time.

The pragmatic mixed-methods approach, which allows for flexibility in gathering qualitative and quantitative data, dominates studies. At times though, it could be argued that this approach was not the most suitable choice for the research questions posed. Some of the most persuasive arguments came from qualitative studies that focused on the experiences of learners, using student voice and rich description.

The enablers for effective STEAM education were consistent across the studies, with the importance of teacher professional development, an interdisciplinary team, connections with stakeholders inside and outside the school, adaptability of the formal curricular structures to facilitate projects, a constructivist approach to teaching and learning and importantly meaningful and equal integration of the arts-based elements of the intervention. Likewise, barriers to effective implantation commonly cited included an over-focus on the STEM discipline at the expense of the arts, low level of self-efficacy and expertise of teachers implementing STEAM, time and resources for projects within pressured formal curricula, a unified and mutual understanding of STEAM education and a lack of leadership or practitioner support for STEAM education.

Most of the studies selected focused on one STEM discipline with a specific arts-based domain. There was an element of consistency noted across the integration of disciplines. For example, most of the science studies integrated with drama, mathematics with music and computer science was integrated with music and/or dance. There were few studies integrating visual arts with any of the STEM disciplines. A few studies on makerspaces and engineering and arts were discussed.

In some cases, the term arts ‘infused’ or arts ‘informed’ was used to fit the project into the domain of STEAM education, but in many cases the integration of the arts, as the terms suggest was limited. Many of the studies included a research question, which addressed a cultural concern or question around representation and inclusivity within STEM education. This is important as gender, race and social class can intersect to create a persistent hegemonic STEM landscape in schools and in society. Few studies focused solely on critical perspective usually including a measurement on learning, attitude or interest in STEM/STEAM education.

The review of literature at post-primary highlights the need for a broadening of the domains of integration within STEM and across the arts. That said, studies that tried to do too much, too soon, such as those that attempted to implement a whole school approach to STEAM were counterproductive in some cases. This review highlights that the literature focus related to STEAM education is at an exploratory and early phase. There is significant scope for innovation and creativity regarding research focus, design, and implementation of STEAM education interventions.

Subsection C - Effective STEAM Education Interventions in Informal Education Settings

A variety of alternative terms were used within the informal STEAM education research including *out of class educational experiences* (Stagg and Verde 2019), *non-formal learning contexts* (Trott et al 2020) and *non-traditional learning environment* (Hunter-Doniger 2020). The contexts in which such STEAM education occurred included workshops, after-school clubs, museums, and summer camps.

Similar to the formal STEAM education studies, the informal STEAM education research tended to focus on integrating an arts subject with a single STEM subject; however, there were more instances within interventions of more integration of the arts with at least two STEM disciplines. There is much diversity regarding the context of the studies and prominent discipline groupings. Equally, the particular approach taken within interventions varied substantially. The arts subject that featured the most across the studies was the visual arts followed by the dramatic arts. While initially there were 40 articles included that fit into the informal education setting, preliminary analysis of these resulted in this number being cut further to 20 research studies. Mirroring the approach taken in previous sections, the informal STEAM education research studies are presented according to the relevant arts area and STEM discipline(s) integrated.

VISUAL ARTS AND SCIENCE

The following table presents the research studies that explored the integration of the visual arts within STEAM projects. When the visual arts were integrated with a single STEM discipline, it tended to be science. However, the majority of studies evidenced the integration of the visual arts with more than one STEM discipline. Subsequently, the range of studies are evaluated.

Visual Arts and Science	
1	Hunter-Doniger, T. (2020). Seeing the forest through the trees: at the intersection of Forest Kindergartens and art-based environmental education. *Journal of Adventure Education and Outdoor Learning.*
2	Trott, C.D., Even, T.L. and Frame, S.M. (2020). Merging the Arts and sciences for collaborative sustainability action: a methodological framework. *Sustainability Science*, 15: 1067-1085.
3	Klein, J.L., Gray, P., Zhbanova, K.S. and Rule, A.C. (2015). Upper Elementary Students Creatively Learn Scientific Features of Animal Skulls by Making Movable Books. *Curriculum & Instruction Faculty Publications*. 13.
4	Ofori-Boadu, A., Deng, D., Stephens, C.M. and Gore, K. (2019). *Learning Experience and Self-Efficacy of Minority Middle School Girls during a Bio-char Modified Cement Paste Research Program at an HBCU*. Paper presented at 2019 American Society of Engineering Education (ASEE) Annual Conference and Exposition, Tampa, Florida.

Table 29 - Evaluation of STEAM Education Literature in Informal Settings: Visual Arts and Science

A relatively large number of informal STEAM studies integrated the visual arts and science. While the initial studies examine STEAM projects in different informal education settings that targeted participants from low socio-economic backgrounds, the final project specifically targeted girls.

Hunter-Doniger (2020) reports on a case study of 20, 8-10-year-old US children's engagement in a *week-long art-based environmental educational summer camp*. These children came from a school with a low socio-economic status. In this camp, a child-centred approach was adopted, where the children spent the majority of their time engaging in free-play, exploring the hiking trails in the forest. They were encouraged to explore ideas through hands-on learning and given a sketchbook to record their learning. The camp counsellors' role was to support investigation through probing and encouraging children to document their observations.

Qualitative data were collected using field notes, artefacts and brief informal group interviews. The findings suggest that while the children initially demonstrated negative reactions to nature, they subsequently became more comfortable with the environment. They also responded poorly to the sketchbooks as they were awkward to carry. However once they learned how to use them, they used them efficiently to document their observations and thoughts. In this context, children seemed unaware that they were learning, empowered to lead their own investigations assuming the role of both scientists and artists where they used drawings and words in their sketchbooks to record their discoveries. A collaborative learning environment was established where children shared their observations with their peers. Science and art learning occurred simultaneously, with each activity having a deliberate cross over; for example, children made a nature sculpture after sorting leaves, pinecones and rocks. An enabler in this study was student agency as the children chose what they wished to explore; resulting in optimal motivation to engage and ownership over the focus. A barrier to such experiences is the overuse on formal activities within formal education.

Trott et al. (2020), explore an arts and science integration targeting sustainability education across two case studies, using the artform of digital photography. The western US case study, a 15 week after-school programme (one-hour session weekly) called '*Science, Camera, Action!*' worked with 10-12 year-olds (n=55) within a national non-profit boys and girls club using digital photography and hand drawings. The Haiti case study, an art centre course called *Photo Environment*, worked with a total of 21 youths (cycle one: 8-14 years (15 weeks, one session per week), cycle two: up to 21 years (eight weeks, 2/3 sessions per week) used digital photography and documentary film making. Both case studies promoted transdisciplinary learning centering on real-world problems, where participants made personal connections to local sustainability issues. 'Photovoice,' an arts-based methodology, was used within the participatory action research, to promote participants to become increasingly aware of and respond to the selected challenges.

In this US programme, a university-community partnership introduced a collaborative, community-based programme called *Science, Camera, Action!* addressing climate action to children within three Boys and Girls Clubs (non-profit organisation serving youth most of whom live in poverty). After engaging in activities and games exploring the social and scientific dimensions of climate change, the participants used programme-provided digital cameras to take photos that communicated their ideas and emotions about each programme topic. About half of the participants received introductory training in photographic techniques during a field trip. Where participants forgot their cameras, they were asked to draw their observations. At various stages during the course, participants engaged in a photovoice group discussion where they spoke about their printed photographs, prompted by focus questions such as ‘What do you see here? What can we do about it?’ Finally, participants received support to design and implement family and community focused ‘Action’ projects. After viewing a compilation of the group’s favourite photographs, participants brainstormed action ideas. The programme facilitators recorded all ideas and shared them back, thus facilitating participants to discuss their preferred action project ideas e.g. raising awareness among local adults (exhibition, website), community garden and engage with policymakers (presentation). Most of the action projects were completed within the 15-week programme period. For the participants who created a community garden, a summer garden club was established to allow them to continue working on this.

In the southern Haiti case, a university-community partnership within a community Arts organisation sought to incorporate STEAM into an otherwise Arts-focused programme. This resulted in the development of the *Photo Environment* course, which aligned with the ongoing work of the Arts centre educator who had been creating a documentary about the issue of clean water in the region. The course content integrated science topics (water systems, quality, management) with the arts (digital photography). Activities included using digital cameras to represent and communicate local problems related to clean water, and as a means of responding to the issue through community action. As part of the programme, youths went on day trips to local water sources (streams, rivers, open community cisterns), to photograph problems with these water resources and to collect water samples for testing. Throughout the programme, youths discussed their photographs focusing on the natural beauty, the consequences of climate change and pollution and viable changes. The water testing was many participants’ first opportunity to gather evidence, make hypotheses and analyse the results and promoted further understanding of the problem. In terms of action, alongside organising and holding photography exhibitions of their own local water-focused photography and the results of their water testing, water test analyses were also presented to local community members and policy makers. The students also produced and screened a brief documentary style film describing the programme and featuring the voices and actions of both youth and educators. In cycle 2, participants began alerting neighbourhood residents in areas where water was polluted.

In both case studies, focusing on local action opportunities served as an enabler, empowering participants to connect with scientific concepts relevant to their lives. Equally, photography served as an enabler, supporting participants in connecting affectively with the local problem and supporting them in communicating. These components resulted in participants being galvanized to collaboratively act to make positive changes in their local community, thus emphasising the transformative capacity of creative expression. A barrier identified was that in both cases, the process was not genuine participatory engagement from the start, where the problem was identified by the programme organisers as opposed to the community partners i.e., the participants (Trott et al. 2020).

Klein et al. (2015) reports on a craft-focused study of nine 9-12-year-old participants, as part of a *week-long summer camp at a local university,* engaged *daily in a 75-minute lesson where arts was integrated with science*, focusing in particular on animal skulls. Crafting demonstrated a co-equal focus on developing visual arts education and science education outcomes simultaneously. In each lesson, after sharing their prior knowledge, being introduced to the relevant concepts, and examining the animal skull replicas, participants worked to use their knowledge of animal skull concepts, focusing on their form and function, to make a page of their moveable book. The participants incorporated various features e.g., pop-up constructions, lift-the-flap and also created their cover art, related to the Mexican Day of the Dead. Their skull made from recycled household materials was completed for homework. Data were collected using pre/post-test of science knowledge, where identical instruments (six items) were used at the start and end of the intervention. Identical attitude surveys (five items) were administered at the end of lesson three, four, and five. The findings report a significant improvement in participants' knowledge about animal skull structure (paired sample t-test, $p< 0.0001$). The attitude survey reports consistently high levels of enjoyment and motivation alongside perceptions of being highly creative across the measurement points. These findings were supported by observations across the week. This study evidences how arts integration with science in the form of hands-on craft-making can motivate high levels of student engagement and support strong retention of knowledge. This study reflects the value of ‘design and make’ type activities, which would be central to knowledge and skill development in most science curricula, and in this case incorporates a creative element into the process.

Ofori-Boadu et al. (2019) report on the impact of a one-week STEAM programme, funded by the Engineering Information Foundation, *targeted at tackling under-representation of minority women in engineering and technology careers*. The programme *STEAM Activated!* targeted marginalised middle school girls (n=22). The programme focused on bio-char modified cement paste research experiences. For all activities across the week (lectures on cement and concrete, laboratory experiences to investigating the influence of bio-char on strength/water absorption characteristics, field trips, engineering education seminar, oral STEAM presentations), personnel were either female and/or from racial minority groups, thus giving participants opportunities to interact with STEM professionals of similar minority characteristics. The active nature of the programme alongside opportunities to engage with relatable role models were both powerful enablers. The participants were encouraged to integrate their preferred arts into their STEM projects and presentations e.g. using rap or cultural art to communicate their understanding.

This qualitative study gauged the effect of the programme on learning and self-efficacy, with data collected using a knowledge post-test alongside a self-reporting survey with open-ended questions after each activity. The findings suggest that the programme improved participants’ knowledge about cement and concrete materials, with a mean post-test score of 78%. Participants also self-reported engaging in the programme had resulted in gains in their self-efficacy, with 86% of them expressing a desire to persist into engineering and technology careers. To this end, they made commitments to actions to increase their STEM knowledge and to increase women and minority participation in engineering and technology disciplines. While in the presented *STEAM Activated* programme, authentic arts experiences were not an integral part of the process, but rather participants received isolated opportunities to engage with the arts (decorating their cement paste frisbees or communicating their understandings of STEM). Therefore, while described as STEAM, a barrier was that the arts were not integral to the project, but rather an add-on. There is further potential for visual art education (alongside other arts education) to develop their learning further, for example connecting to a design project that was personalised. Across the informal STEAM interventions that integrated the visual arts and science, the enablers and barriers are summarized in the following table.

Enablers in Visual Arts/Science - Informal STEAM Education	Barriers in Visual Arts/Science - Informal STEAM Education
• The inclusion of the visual arts as a means of learning • The inclusion of the visual arts as a means of creative expression to communicate messages and emotional responses • The use of a transdisciplinary approach that centres on a real-world problem rather than a discipline • Allowing students to identify a problem they wish to examine/ address • Connection making with local issues • A participatory approach using a bottom-up process promoting full and active participation of learners in pursuit of shared meaning making and solution paths • Opportunities to act as change agents • The involvement of an interdisciplinary team in the development of informal educational experiences • Student-led projects where participants have choice regarding the focus of their exploration, promoting motivation and ownership • Opportunities to develop both visual arts and science understandings/ skills co-equally	• Failure to promote genuine participatory engagement from the outset • Insufficient time and opportunity to develop visual arts understandings and skills • Arts education contribution is limited to communicating STEM understandings • Closed structure activities that fail to promote agency and ownership of learning among participants.

Table 30 - Enablers and Barriers Identified in Visual Arts Based and Science Literature within Informal STEAM education

VISUAL ARTS AND TECHNOLOGY

There was only one informal STEAM education research study that integrated the visual arts and technology.

Visual Arts and Technology	
1	Peppler, K.A. (2010). Media Arts: Arts Education for a Digital Age, *Teachers College Records*, 112(8): 2118-2153.

Table 31 - Evaluation of Informal STEAM Education Literature: The Visual Arts and Technology

In this study, Peppler (2010) examines 30 participants' (age 8-18) experiences and learning while engaging in *artistic practices using the media arts software Scratch* within a *Computer Clubhouse* in South Los Angeles. The Clubhouse learning model promoted self-directed learning, where participants pursued any project they chose, in line with their interests. Through this, participants transitioned from being the consumers of media to active producers of it.

This qualitative study used both participant and professional media artist interviews, archives of participant media art and video recordings of over 30 case studies of participants in the process of making media art. The findings suggest that the approach promoted participants to make connections with other art forms. For example, while a strong foundation in the visual arts is not needed to engage in media arts, working in the digital medium can lead to productive engagement in arts education, where participants confront some of the same considerations associated with formal instruction in traditional arts including perspective, colour, shape, drawing from observation. Participants also made explicit connections to various academic subject areas. The study also found that the bottom-up approach utilised promoted the development of a community of media artists who used peer sharing to disseminate ideas/approaches with others both locally as well as more widely through a distributed network. Media art was found to broaden participants' traditional experiences of the arts and combine different art types alongside content from various subject areas. Participants advocated that there were no boundaries to genres of media art that could be created on Scratch.

An enabler within this study was participants' complete autonomy over the focus or the structure of their Scratch project, which was found to encourage agency and active learning among participants. While projects that were original were valued more by professional media artists than those that merely showcased high quality emulations due to their artistic integrity, a barrier in this study was that many of the original pieces did not reach their potential because of a lack of artistic instruction due to limited opportunities for high quality interactions with more expert peers. Peppler (2010) questioned whether emulation could be a steppingstone in order to develop the relevant skills to subsequently support participants in creating original media art.

The enablers and barriers that were evident within the visual arts and technology study are summarised in the following table.

Enablers in Visual Arts/Technology - Informal STEAM Education	**Barriers in Visual Arts/Technology - Informal STEAM Education**
• Digital art naturally connects to youth culture and students' interests • Opportunity for students to express themselves • Opportunities for active learning • Digital arts support multiple entry points and the production of different genres of work • Open-ended, student-led experiences promoting agency • Opportunities for trial and error • Peer teaching and learning opportunities • Opportunities to emulate in order to develop the requisite arts skills required to create original responses • Professional development to support those teaching digital art • Access to software that is cross platform, open-source or free promoting the use of these technologies	• Lack of relevant expertise to support learning within the informal education setting • Inadequate and unequal extended access to creative technologies • Limited focus on the visual arts skills • Lack of time and/or opportunities to develop new visual arts knowledge or skills • Originality and creativity may be a struggle for participants due to limited experience or understandings

Table 32 - Enablers and Barriers Identified in Visual Arts/Technology in Informal STEAM education

VISUAL ARTS AND TWO OR MORE STEM DISCIPLINES

Although some studies focused on integrating the visual arts and one STEM subject, the majority of the informal STEAM education research that incorporated the visual arts studies reported on its integration with more than one STEM subject. While these interventions span the spectrum of contexts, formats, and foci, the final two studies in this section intentionally targeted girls.

Visual Arts and two or more STEM disciplines	
1	Parekh, P. and Gee, E.R. (2018). Zooming into a Tinkering Project: The Progression of Learning through Transitional Objects. *Interdisciplinary Journal of Problem-Based Learning*, 12(2).
2	Salmi, H., Thuneberg, H., Bogner, F.X. and Fenyvesi, K. (2021). Individual Creativity and Career Choices of Pre-teens in the Context of a Math-Art Learning Event. *Open Education Studies*, 3: 147-156.
3	Rudd, J.A., Horry, R. and Skains, R.L. (2020). You and CO_2: A Public Engagement Study to engage Secondary School Students with the Issue of Climate Change. *Journal of Science Education and Technology*, 29: 230-241.
4	Nitsche, Michael and Crystal Gillett (2020). Framing Craft and Performance in Hybrid Puppetry Workshops. *Design and Technology Education*, 25(1): 96-116.
5	Kuznetsov, S., Trutoiu, L.C., Kute, C., Howley, I., Siewiorek, D. and Paulos, E. (2011). *Breaking Boundaries: Strategies for Mentoring through Textile Computing Workshops*, In CHI 2011- 29th Annual CHI Conference on Human Factors in Computing Systems, Conference Proceedings and Extended Abstracts ([pp. 2957-2966). Conference on Human Factors in Computing Systems- Proceedings).
6	Dixon, C., Schimpf, C.T., and Hsi, S. (2019). *Beyond Trial and Error: Iteration-to-learn using computational papercraft in a STEAM camp for girls*. Paper presented at 2019 ASEE Annual Conference & Exposition, Tampa, Florida. 10.18260/1-2—32153

Table 33 - Evaluation of Informal STEAM Education Literature: The Visual Arts and Two or more STEM disciplines

Parekh and Gee (2018) report on a design experiment exploring the implications of learning while making within a *pop-up maker space* that ran twice monthly in the children's *play space of a public library* in the Southwest of the US. In these 90-minute sessions, participants (aged 4-12) used everyday materials, art and craft supplies and broken toys to make toys related to the theme 'toys that move or fly' that they could take home after the session. Over two years, 216 children participated in the sessions, where some only attended one session whereas others attended multiple sessions. Adults accompanying children sometimes engaged in tinkering alongside their children. While data were collected from multiple data sources including field notes, photographs of progressions in projects, brief video clips and conversations with participants, this paper explored one child's developing understandings of materials and corresponding changes in the designed object. It was evident that the child made several modifications to the project and changed their design plan twice during the session. Through the process of creating, testing and evaluating prototypes, identifying problems in his design, brainstorming solutions through collaboration and refining the design, the child demonstrated emerging and more sophisticated understandings of the features and properties of various materials, moving beyond surface features. Hence, the activity integrated visual art, engineering, science and technology. The authors suggest that the informal and open-ended design served as an enabler allowing participants to engage in creations of interest to them, challenging shifts in understanding, thus laying the foundations for more formal introduction of scientific and engineering principles.

Salmi et al. (2021) report on a study of 392 elementary students (age 12-13 years) across 11 different Helsinki schools who completed a 140-minute workshop on a university campus that integrated visual art, engineering, science, and technology. Groups of 2-4 students were given a *4D frame educational toolkit* that consisted of hundreds of plastic tubes and connectors. After an initial brief introduction, groups could use the time to trial, design and build freely. Groups were tasked to design and create an original geometric structure that was no bigger than 20cm x 30cm x 40cm, which preferably had moving parts and obtain energy from the wind. An overall plan was required consisting of basic drawings and brief explanations. Students were encouraged to test their constructions and modify plans accordingly throughout the process. A pre/post-test design, using the Science Motivation Questionnaire (Bakerman 2005), demonstrated that engagement in the STEAM workshop positively affected participants' career choice preferences and that creativity level had a supportive role (significant relationship). This informal STEAM education workshop required participants to apply their knowledge across various STEAM disciplines in order to complete the task, to create a unique and individual interpretation and construct a unique model. The open-ended nature of the task was considered an enabler, providing participants with the freedom to create, test, problem-solve and refine their constructions. While acknowledging the merits of this approach, there is further potential for intentional arts education; for example, if prior to the task, students were introduced to the use of geometric forms in art and design to help extend their understanding and appreciation of the function of geometric forms and in turn their designs.

In Rudd et al.'s study (2020), the multi-disciplinary STEAM programme, *You and* CO_2, was presented to secondary students from relatively affluent backgrounds across two different schools in Wales (School 1, n=85, age 13-14; School 2, n=95, age 12-15). The programme consisted of three inter-linked workshops developed by the researchers, combining the science of climate change and arts-based approaches. The first workshops introduced the role of carbon dioxide in climate change and analysed the carbon footprint of everyday activities, exploring possible means of reduction. In the second workshop, the concept of digital fiction was introduced prior to whole class exploration of the interactive custom-written digital fiction 'No World 4 Tomorrow' (www.youandco2.org), where the students made choices about how the characters behave, promoting debate regarding decisions. Subsequently pairs explored digital fiction further, searching for as many endings as possible in light of different decisions for the characters. Prior to workshop three, students were asked to plan their storyline for their own climate change digital fiction, which they produced on Twine (https://twinery.org) during workshop three. Technical support was available from online tutorials contained within the project website as well as from the research team. While in school 1, there was a month between each session, in school 2, sessions occurred on three consecutive days. Reflections and feedback from school 1 informed modifications to the programme for school 2; resulting in more interactive sessions.

Data included researcher reflection, participants' original digital fictions and a specially developed five-item 'Attitudes to Carbon Footprint Reduction' (ACFR) scale (4-point Likert scale) that was administered at four stages across the programme (before workshop 1 and at the end of workshops 1, 2, and 3). The evaluation findings suggest that the workshops were well received by both teachers and students. Common themes within school 1 were tourism (modes of transport), plastic waste and pollution, whereas in school 2 food choices was a recurring theme, suggesting that participants had incorporated the contents of the workshops alongside understandings not addressed. The comparison of participants' attitude across the *You and CO2* workshops suggests that participation was associated with some small positive changes in students' Attitudes Toward Carbon Footprint Reduction Scale' scores, with significant differences evident in the attitudes among School 2 participants from pre to post. The main enabler within this programme was the student-led nature of the sessions, where across the workshop participants had autonomy regarding the focus and direction of group/pair work and digital fiction project, thus empowering them to acknowledge the role of humans and identify meaningful positive actions to address their carbon footprint. Large class sizes, limited time to brainstorm digital medial story-line ideas and issues with access to technology (for example, the need to share computers alongside inadequate technical support or internet connection) were reported as barriers to optimum engagement.

Two studies focused on the use of crafting within STEAM interventions. In the first study, Nitsche and Gillett (2020) report on the evaluation of the final version of *Prototyping Puppets* workshop, funded by the National Science Foundation, which integrates puppetry with science (electricity). Within this study, following a 45-minute preparation session with teachers and a week lapse to promote preparation for the session, two extra-curricular workshops were administered to fifth grade students (extra-curricular workshop in a charter school n=11; afterschool robotics club n=12) from Georgia. The first (extra-curricular workshop) was led by an experienced teacher with extensive relevant expertise in crafting and electronics, whereas the second workshop (robotics club) was co-taught by two experienced teachers, one a STEM teacher and the other an art teacher. In the three-and-a-half-hour-long workshop, where after learning basic electricity concepts, and collaboratively creating a shared story, students build customised hand puppets (that include simple circuits) as characters for the story. Students used their puppets in a puppetry show to act out their shared story and test their technology.

Data were collected on changes in participants' self-perceived attitudes to electronics and craft/art using a pre/post Likert-scale questionnaire, post-survey items to gain feedback on workshop activities, field notes and interviews. While slight differences in experiences were reported by participants in the respective workshops, overall, the findings suggest that participants in both student-led workshops reported improvements in their perceived knowledge of and attitudes to both technology and arts and craft. The workshop was extremely well received, with participants emphasising their appreciation for opportunities to collaborate and work as a team during the making and performing parts. This is evidenced by the high rating of workshop activities, with the highest level of agreement evidencing participants' desire to engage in another workshop. Participants also acknowledged that they were challenged by the workshop. A particular feature of this workshop was its capacity to realise STEM and arts goals simultaneously.

In the second 'crafting' STEAM study, Kuznetsov et al.'s (2011) explored the experiences of seven *at-risk middle school girls* (age 10-12) who participated in a set of five weekly workshops (1½-2 hours) within a local outreach organisation in Pittsburgh. The workshops engaged the girls in ideation, design and creation of personal wearable computing projects incorporating electronics. The workshops took place within a university design studio. Given previous experience of the girls quickly losing interest and becoming uncooperative during lecture-style sessions, the workshops were active, promoting iterative design, critique and hands-on making practice. The workshops explored basic circuit components (LEDs, buttons) (Workshop 1) and programming the LillyPad Arduino (Workshop 2), prior to choosing an item they wished to modify into a LillyPad Project such as a t-shirt, belt, or teddy bear. Girls then brainstormed and designed their wearable electronics using paper prototypes on a whiteboard identifying the positioning of LEDs, sensors, buttons, Arduino, battery etc., as well as colour coding the connections between pins to create a circuit (Workshop 3). After presenting their designs to the group, the girls implemented their design (Workshops 4 and 5). The implementation phase involved placing all the hardware on their item and using fabric glue to fix components and sewing on the pins with conductive thread. Throughout this process, the girls adapted their plans in light of time available issues faced (e.g., need to scale down or resize layouts). Once all the components were attached, the girls worked on writing their Arduino programme. For the most part, the girls worked independently but enjoyed interacting and sharing ideas with each other in groups or during presentation. Overall, the teaching style was bottom up, or student-led. Where necessary they requested support from workshop volunteers, who assumed the roles of helpers asking the girls how their project should function rather than telling or directing them. However, due to time constraints, volunteers took the lead in troubleshooting any issues with circuits and programmes. As the workshops took place over the summer, attendance proved a barrier, varying weekly between four and seven girls. This resulted in only four girls attending enough sessions to finish the final project.

Data collection included audio recording of workshop sessions, photographs of designs, as well as individual staff interviews and group participant interviews a week after the final workshop to gauge their perceptions of the workshops. During interviews with the girls, they were generally uncooperative and demonstrated extremely limited enthusiasm for the project. However, the data collected during the workshops alongside staff interviews identified that the girls took control and ownership of their work and were proud of their designs. The outreach staff identified a potential barrier; the requirement for a creative response as a new and challenging aspect for the girls. To address this alongside the time limitations, staff suggested extending the workshops to eight sessions, where the first four allowed the girls to complete the same project to develop the relevant knowledge and skills, prior to engaging in their own original creations in the subsequent 4 sessions. Thus, an identified enabler going forward would be the opportunity for the girls to practice the relevant skills prior to creating their own unique designs. This recommendation reflects that of Peppler (2010) earlier regarding emulation. This is in keeping with the skill development focus in most effective science curricula.

Dixon et al. (2019) present an exploratory study of four elementary school girls (age 9-11) who engaged in a design activity using computational papercrafts in the context of a *museum-based STEAM summer camp for girls*, supported by the NSF. The girls were from the urban area close to the museum and were from middle and upper middle-class backgrounds. The theme of the camp was *The Fun of Flight* where campers engaged with different related projects. This study focuses on a computational papercraft project where the girls were asked to make a paper mechatronic bird of their choice, involving the design and construction of paper wings and cardboard sculptures with gears and linkages powered by servo motors. The research explored the practices of these novice designers as they tested and refined their ideas and prototypes, focusing in particular on the influence of making materials accessible and abundant on participating girls' engagement in testing and refinement. The girls also had access to a free and open source, web-based gear simulator called 'Fold Mecha' and a customized circuit board called 'Locotap'. The girls initially hand sketched the creatures they wanted to create and considered the type of motion this creature would have. Over the course of a day, the girls developed their designs in response to the project theme, then worked with mechanics, electronics, and craft to enact their vision. Over the subsequent two days, they continued to tinker with their designs to create a working version that would be included in the public exhibition. There was one main camp instructor and three assistants, one of whom had experience of computational papercrafts; however the others had experience with education, engineering, and crafts.

While data were collected using structured interviews (staff and girls), observation (video) and audio recordings (interactions at workspaces) as well as students' intermediary design documents and final artefacts, this paper focused on students' retrospective interviews and audio recordings during design sessions. The findings reveal ways in which testing and refinement were supported in the learning environment. Firstly, participants used the online modeler Fold Mecha for simulation later in the project than anticipated by the researchers, to help them troubleshoot problems that arose or to generate new ideas once aware of the limitations of their design. In cases where the online tool could not simulate the design solution, the girls sought support from the facilitators who supported their understandings by creating mock-ups and explanations of the expected outcome. These structures facilitated 'trial-before-error.' Secondly, novice designers were supported in realising that their artefact comprised of connected but independent systems through the use of different materials and structures in the design space e.g., separate testing stations for each subsystem. Hence, the researchers reported that this approach supported the girls to take 'small bets' engaging in focused testing of a particular subsystem. Consequently, students' designs progressed even when not all areas were resolved. The use of relatively inexpensive materials such as cardboard also supported the girls in being more open to testing multiple ideas. Hence, the findings suggest that the materials and targeted supports used served as enablers to the girls' problem-solving and tinkering, promoting a culture where the girls embraced learning from testing.

The identified enablers and barriers for the informal STEAM education research involving the visual arts and at least two STEM disciplines are summarised in the following table.

Enablers in Visual Arts and two or more STEM - Informal STEAM Education	**Barriers in Visual Arts and two or more STEM - Informal STEAM education**
• Open-ended tasks that supported student-led responses • Hands-on experiences • Promotion of engineering design process- testing and refining • Peer teaching and learning opportunities • Opportunities to emulate in order to develop the requisite skills prior to the requirement for creative, original responses • Access to software that is cross platform, open-source or free promoting the use of these technologies • Access to supports in the form of technology programs • Use of inexpensive materials/technology to promote access to experiences and openness to the iterative process • Access to expertise to support the development of the relevant concepts and skills • Ample time to support students to brainstorm/trial ideas	• Time limitations for intervention planning and implementation • Low levels of participation in informal education interventions • Technical issues e.g. internet connectivity • Lack of access to technology • Limited technical support during intervention/project. • Lack of time and/or opportunities to develop new visual arts knowledge or skills • The development of originality and creativity may be a struggle for some participants due to limited experience/understandings

Table 34 - Enablers and Barriers Identified in Visual Arts and two or more STEM Disciplines within Informal STEAM education

PERFORMING ARTS AND SCIENCE

This section presents the research that explored the integration of performing arts (drama, music and dance) within informal STEAM education projects. All the research studies that used the dramatic arts within informal STEAM education projects paired with the STEM discipline, science. In contrast, musical arts, and dance-based arts while less prevalent within STEAM interventions were integrated with a greater variety of the STEM disciplines.

Performing Arts and Science	
1	Stagg, B.C. and Verde, M.F. (2019). Story of a Seed: Educational theatre improves students' comprehension of plans reproduction to plants in primary science education. *Research in Science and Technological Education*, 37(1): 15-35.
2	Stagg, B.C. (2020). Meeting Linnaeus: Improving comprehension of biological classification and attitudes to plants using Drama in primary science education. *Research in Science and Technological Education*, 38(3): 253-271.
3	Peleg, R. and Baram-Tsabari, A. (2017). Learning Robotics in a Science Museum Theatre Pay: Investigation of Learning Outcomes, Contexts and Experiences. *Journal of Science Education Technology*, 26: 561-581.
4	Ruiz-Mallén, I., Gallois, D. and Heras, M. (2018). From White Lab Coats to Actual Scientists: Exploring the impact of researcher interaction and performing Arts on students' perceptions and motivation for science. *Science Communication*, 40(6): 749-777.
5	Ward, S.J., Price, R.M., Davis, K. and Crowther, G.J. (2018). Song writing to learn: how high school science fair participants use Music to communicate personally relevant scientific content. *International Journal of Science Education*, 8(4): 307-324.

Table 35 - Evaluation of Informal STEAM Education Literature: Performing Arts (Drama, Music & Dance) and Science

Four of the studies in this section explore varying approaches to integrating the dramatic arts and science. The particular features that of these interventions that serve as both enablers and barriers are identified as appropriate.

In the first dramatic arts and science article, Stagg and Verde (2019) report on a study that examines how a 50-minute interactive theatre performance of the play *Story of a Seed* impacts the 144 participating UK Year 5 and 6 students' (age 9-11) knowledge of plant reproduction and attitudes to plants. A pre-requisite to class selection was that students had not yet studied Key Stage 2 plant reproduction from the UK national curriculum. Schools were selected to ensure a diverse sample of students in terms of ability, socio-economic status and location. The play was written by Stagg and three members of the participatory arts company (www.blazingtales.co.uk). The play was not designed to replace formal classroom instruction but to create a funny and entertaining play to introduce students to the topic, stimulating their interest and appreciation of plants and to develop their knowledge of plant reproduction. The play was performed in the school hall of the selected classes during the school day towards the end of the school term. The play features two plants (played by two professional actors) who introduce the students to floral structure, pollination, fertilisation, seed dispersal and germination, using props and a customised song 'Ballad of the Seed,' where rhyming verses and the chorus capture key points. Regular audience participation is invited throughout the performance to promote active learning using three participatory arts activities: making tissue paper flowers (after flower structure scene), creative writing about seeds (after seed formation scene) and rain-making sound dance (after the seed dispersal scene).

A mixed method approach was adopted, where data collection included pre- and post-intervention questionnaires (measuring knowledge and attitudes) alongside follow-up interviews (n=30). While six classes participated, three of these classes were in study 1 (n=80) and three in study 2 (n=64). The approach to the two studies were identical in every way except for the format of the knowledge section of the questionnaire. For each study, the content of pre- and post-intervention knowledge and attitude sections of the questionnaire were identical. The post-questionnaire contained an additional section seeking feedback. A subset (n=27) of those within study 2 took a delayed post-test six weeks afterwards to measure the long-term effect on knowledge and attitudes. Comparison of pre and post-tests indicated significant gains in knowledge for students in both studies ($p< 0.001$). Comparison of immediate post-test and delayed post-test indicated no significant difference, suggesting that the knowledge gain, evident in the immediate post-test had persisted over the long-term. Students also perceived that engaging with the interactive play helped them to learn and was enjoyable; highlighting particularly memorable aspects of the play that appealed to them and supported their understanding of the concepts included the use of humour, prose, song, and props within the play as well as the participatory arts activities. While students' attitudes to plants improved significantly, these were not substantial. Within this research, enablers included the use of humour, song and active participation. However, participating students did not have ample opportunities to actively create drama or develop relevant skills.

In the second dramatic arts and science article, Stagg (2020) reports on a study examining the impact of an *immersive drama workshop* on 108 participating UK primary grade 6 (age 9-10) students' understandings of biological classifications and attitudes to plants. This was a free enrichment workshop for classes who had not yet studied Key Stage 2 biological classification from the UK national curriculum. The 90-minute drama workshop, produced by a theatre-in-education company director and the researcher, was *informed by the life of an 18th century biologist, Linnaeus*. The workshop took a process drama approach, set in 1735, where the actor-educator playing Linnaeus was recruiting 'apostles' to send on an overseas specimen-hunting expedition. The actor facilitated the session, and the researcher took on the role of an 'apostle' that provided Linnaeus with assistance. This involved the actor-educator 'teaching in role,' guiding and supporting students, with both scripted and improvised elements. Therefore, the participating students were immersed in the scenario, engaging in a series of challenges (three drama-games (Ambition (mime), Explorer (role play), classification) and two small group activities (classification of potted wild plants, create scientific names for a plant specimen) to demonstrate their suitability to become apostles. Data collection was also built into the narrative of the drama.

A mixed method approach was taken. Quantitative pre- and post-intervention measurements of knowledge of biological classification (Peleg and Baram-Tsabari 2011) and attitudes 'Plant Attitude Questionnaire' (Fancovicova and Prokop 2010) were collected, where the items were identical for both administrations. The quantitative data collection was packaged in a questionnaire format and the post-questionnaire included two additional closed questions (Did you enjoy the workshop? Did the workshop help you learn?) and two open questions (What did you like most? What did you like least?). Interviews (n=72) were conducted one week later to further reveal the impact of the experience. Knowledge data were collected from 23 students two months later to measure the long-term learning outcomes.

The findings of the pre/post intervention comparison indicate statistically significant increases in both attitudes towards plants (Wilcoxon signed rank: $p<0.05$ for all dimensions) as well as knowledge ($p<0.001$). While there was evidence of loss of knowledge among students who completed the delayed post-intervention test, these test scores were significantly higher than the pre-test ($p<0.001$). The study also reported exceptionally positive responses among participating students. Features students particularly enjoyed and associated with understanding the concepts and positive attitude change were the participatory and practical nature of the experience as well as the opportunity to work with interesting or novel living potted plants (as opposed to pictures or models of plants) to complete genuine scientific inquiry. This project reinforces the widely held agreement on the need for hands-on minds-on inquiry-based approaches to plant science. Hence, the participatory nature of the process drama alongside opportunities for related hands-on scientific investigations within the context served as enablers facilitating students to develop of relevant knowledge and attitudes to plants within an authentic drama experience. In this study, both science and dramatic arts were valued and engaged in co-equally.

In their article, Peleg and Baram-Tsabari (2017), report on an exploratory study that explores the potential educational value of a *commissioned science museum theatre play Robot and I* to *accompany an exhibition on robotics in a major science museum* in Israel. On consultation between the play's writers and the museum's educational staff, the educational goals of the play were to support children aged 5-9 years to understand that a robot needs a motor, sensors, and a computer, that robots can help humans in many ways, that children can be inventive and design things including simple robots and that robots are not human and do not have emotions. The resulting play was a one-actor show, featuring a young child, who designs little robots from everyday materials to help their mother and in the process learns that while robots need sensors, a motor and a brain-like computer and can do many things robots cannot replace their mother's love. In the play, the child imagines they are a robot and saves a cat from a cave and enters a volcano to save a village from destruction.

In order to examine the educational value of the play, data were collected using questionnaires and semi-structured interviews. In a bid to explore the effects of different contexts, data were collected from children who attended the museum play as part of a family group and those who attended as part of a school field trip. For the family context, due to the challenge of administering both a pre- and post-test, a two group post-only quasi-experimental design was implemented, an experimental group who attended the play (n=239, grade 1-4) and a comparison group who visited the museum and did not watch the play. The participants subgroups could be broken further into children who attended the robotics play only (viewers only), the robotics exhibition only (visitors only), both robotics play and exhibition (viewers and visitors), and neither (comparison group). In the school group (six grade 2 and grade 3 classes), a pre- and post-test was completed a week before and after the play (n=76 paired questionnaires). As all children watched the play, there was no control group. For the family group, the interviews took place 3 months after the visit (n=15 children, n=20 adults), to gauge the long-term effect of the experience by phone, whereas the school group were interviewed face-to-face in dyads (n=32) on the school campus for the school group 3-4 weeks after the play.

The findings are mixed in that there was some evidence of learning from the play, given that over half playgoers mentioned at least one of the robot components compared to about a quarter on non-viewers. Several weeks later, only two of the 47 children interviewed mentioned all 3 components, with one child mentioning two components and six mentioning one component. It was interesting that the children did not pick up on implicit messages within the play regarding robots' ability to help humans. However, a significantly higher number of viewers identified ways that robots helped humans with highest levels of understanding among those who attended both play and exhibition. No significant difference between viewers and non-viewers' responses to items examining children's beliefs that children can be inventive and design things. Although children reported relating to the child in the play and appreciated their efforts, they were skeptical of the child's success. Significantly more non-viewers than viewers believed that robots could love people, with 72% of exhibition viewers agreeing relative to 43% of children who engaged in both play and exhibition and 33% of those who viewed the play only. These findings suggest that the robotics exhibition fostered anthropomorphic views whereas the play discouraged them. The overall findings suggest that while higher levels of viewers demonstrated desired knowledge relative to the other subgroups of children, these levels suggested that the desired knowledge was not well accepted by viewers. Further analysis revealed that while the play's explicit learning goals were decoded as intended by children, this was not the case for the implicit learning goals. An interesting finding was that while the children reported a strong identification with the main character in the play, a child, having a child character voice, the information made it less credible. Consequently, viewing children doubted the child's knowledge of robotics which limited their acceptance of the scientific concepts within the play and instead relied on their prior knowledge of robotics. Hence in this context, the use of a child character acted as a barrier. Overall, participants in this study were less active relative to the previous two studies. Also, in terms of STEAM education, a one-sided instrumental approach was adopted where the dramatic arts served to promote science learning, and students received no opportunities to explore the dramatic arts.

The final dramatic arts and science article, written by Ruiz-Mallén et al. (2018), reports on a study that was part of the 'European Commission Horizon 2020' project *PERFORM* (www.perform-research.ed) that included students from five secondary schools in low to middle class areas across three countries (Spain (Barcelona), United Kingdom (Bristol), France (Paris)). The study examined the impact of interactions with researchers and drama-based techniques when learning science on students' perceptions of scientists and their motivations for studying science. Students were asked to be involved in a set of workshops based on inquiry-based learning that used performing arts where students created and performed short artistic shows on scientific topics of interest to them. 135 students volunteered to be involved (64 Barcelona, 29 Bristol, 46 Paris). While the learning outcomes were similar (e.g. improving creativity, critical thinking; fostering positive attitudes to science and perceptions of scientists) across the various countries, variations were evident in workshop lengths, structures and duration. Also, different drama-based techniques were included in the respective settings i.e., Barcelona: stand-up comedy (explain scientific content through storytelling and humour); Bristol: Science busking (students produced a short performance in a public space when scientific contents were explained through practical demo); Paris: improvisational theatre (production of a short science-based theatrical piece). The workshops were designed and facilitated by two science communicators in each setting, and in Paris two actresses also participated. On invitation, across the three countries 15 class teachers and 20 early-stage researchers (PhDs students/postdocs) participated in the workshops and helped students to include scientific content in their performances through dialogue, reflection and discussion. While researchers regularly attended the workshops in Bristol and Barcelona, in Paris fewer researchers participated and were not present for every workshop.

In each school, data were collected from another group of students who did not interact in the workshops (Control group) to facilitate comparison with those who completed the workshops (Perform group). Data were collected for both Perform and Control groups through pre- and post-workshop qualitative surveys. Firstly, students identified three characteristics that came to mind when then thinking about somebody working in science (perform group, n=115). They were also asked to mark an 'x' if they agreed with the statement 'The idea of studying a scientific career makes me feel motivated' (perform group, n=111; control group, n=87). Survey data was complemented with observational data of 'Perform students' interactions and engagement as well as focus group data.

The study found that 'Perform group students' perceptions of scientists became less stereotypical as a result of engaging with the workshops, particularly where they had higher interactions with researchers (Bristol and Barcelona), with a statistically significant reduction in percentage of pupils to list one or more stereotype. While a reduction was also evident among the Control group students, this was to a lesser extent. While the percentage of 'Perform group students' who demonstrated interest in a scientific career increased after engaging in the workshops, French 'Perform group students' interest in scientific careers increased significantly where Drama-based techniques were more frequently used as a pedagogical approach. This trend was not evident among control group students (Ruiz-Mallén et al. 2018). The findings suggest that having researcher involvement in the drama-based methods may enable less stereotypical views of scientists. The limited use of drama as a means of communication with minimal opportunities for participants to develop drama-techniques during the project are identified as barriers. There was one informal STEAM education intervention that integrated the musical arts and science. Ward et al.'s (2018) qualitative study examined 81 high school students' (grades 9-12) use of *music composition* (as part of their projects to the *Student Bio (Biotechnology or Bioscience) Expo* [Science Fair] in the Seattle area between 2004 and 2015) to communicate their understandings of the relevant scientific concepts.

The students' artistic statements were the sole form of data for this study, providing insights into the work. The findings suggest that students made connections between scientific elements and musical elements. For example, rather than merely presenting scientific facts in the lyrics, students also used other musical elements (e.g. genre, musical instruments, and structure (chords, dynamics, melody, rhythm)) to present a scientific topic, convey affect, tell a personal story, and communicate a scientific story (35% of the compositions were instrumental pieces with no words). The study reported that students constructed their understanding of scientific topics in part by constructing music in which scientific elements are mapped onto musical elements (Ward et al. 2018). However, in terms of methodology the study relies solely on self-report data. Hence, within the context of the 'Student Bio Expo,' this music creation opportunity enabled student to use music to express their growing understanding in science. The researchers propose that open-ended song writing exercises may provide alternative routes to support students to process and communicate STEM content. This kind of experience was an optional activity for Expo participants but equally chose to use music in their Expo presentation. Hence, a barrier is that only a select group of students may have such a valuable experience as opposed to gauging the impact of the approach to a range of students with varying levels of interest in science and music. There is merit in all students having opportunities to use musical elements to explore scientific concepts. Across the relevant informal STEAM interventions integrating performing arts and science, the enablers and barriers can be summarised in the following table.

Enablers in Performing Arts/Science - Informal STEAM education	Barriers in Performing Arts/Science - Informal STEAM education
• Opportunity to engage in genuine scientific inquiry e.g. classification within the participatory drama-synthesis of both disciplines • Participatory drama that puts participants in an authentic scientific scenario that requires scientific inquiry reflective of that of a professional scientist • Using performing arts to support conceptual understanding of science concepts • Introduce performing arts techniques during initial teacher education and professional development courses that could be embedded into teaching practices • Promote collaborative planning for integrated experiences involving teams of educators with expertise in a range of STEAM disciplines • Opportunity to develop musical understandings/skills through the process • Opportunity to be creative	• Experimental design is challenging due to the difficulty of recruiting schools as a control group (i.e. not engaging in the Drama experience) • Situations where drama/music is limited to a means of communicating scientific content • Limited opportunities to actively engage in drama creation or to develop and appreciate relevant drama techniques • Limited opportunities to actively respond to or engage with the scientific concepts • Perceived credibility of the characters or the messages within the drama from the audience's perspective • Students not possessing the standard of musical understanding/skills necessary for meaningful participation • Unequal access to STEAM opportunities

Table 36 - Enablers and Barriers Identified in the Performing Arts/Science in Informal STEAM education

PERFORMING ARTS AND TECHNOLOGY

This section presents the research that explored the integration of performing arts and technology within informal STEAM education projects. Among the research projects included, diverse contexts and approaches are evident.

Performing Arts and Technology	
1	McKlin, T., McCall, L., Lee, T., Magerko, B., Horn, M. and Freeman, J. (2021). *Leveraging Prior Computing and Music Experience for Situational Interest Formation*. In SIGCSE 2021 - Proceedings of the 52nd ACM Technical Symposium on Computer Science Education (pp.928-933). (SIGCSE 2021 - Proceedings of the 52nd ACM Technical Symposium on Computer Science Education). Association for Computing Machinery, Inc.
2	Leonard., A.E., Daily, S.B., Jorg, S., and Babu, S.V. (2021). Coding Moves: Design and research of teaching computational thinking through Dance choreography and virtual interactions. *Journal of Research on Technology in Education*, 53(2): 159-177.

Table 37 – Evaluation of Informal STEAM Education Literature: Performing Arts (Drama, Music, Dance) and Technology

There was one informal STEAM education programme that integrated the musical arts and technology. McKlin et al.'s (2021) report on a small-scale study comparing two computer software and music platforms *EarSketch* (http://earsketh.gatch.edu/earsketch2/) and *TunePad* (http://tunepad.live) used by middle school students (age 10-14) in a one-week online summer camp (n=26) called 'Coded Beats' in Georgia. In particular, it explored the unique affordances of each platform in stimulating and developing users' prior music and coding experiences. Both platforms use music as a motivator to learn coding. EarSketch's (also discussed in the post-primary literature) approach is top-down, where students use pre-made segments of music that can be broken up, sequenced together, remixed, recombined and modified using effects to create a new musical composition, where code is written to arrange pre-existing audio loops and effects on a multi-track timeline to create a complete song. In contrast, TunePad's approach is bottom-up, where the student writes code to create songs of individual musical elements (notes (pitches and rhythms) and rests) and assigns these to different instruments to create a musical piece. Both platforms are intended for students with no prior background in either music or coding, and both are designed to provide low floors and high ceilings. However, participants were encouraged to use any prior experiences in their projects. Within the summer camp, participants used both platforms. While the camp curriculum was developed by the researchers, it was taught by an experienced high school computer science teacher. Sessions adopted a three-stage structure starting with 'independent exploration', followed by 'term introduction', where the computer software concepts were introduced and demonstrated, reinforcing the relevant vocabulary. Finally, during 'concept application', participants applied their learning to their own projects. While during the first two days, the camp focused on TunePad, on day three and four, the focus moved to EarSketch, whereas on day five participants finalised their projects (using one or both platforms) for the closing showcase.

In terms of data collection, pre-surveys were used to gauge participants' prior experiences, whereas the post-survey measured triggered situational interest, maintained situational interest and attitudes towards computing. Semi-structured interviews were completed by 15 participants on the final day of camp. Analysis of the pre-survey identified three distinct types of participants- musicians, coders and hybrids. In terms of interest formation, the findings suggest that coders consistently reported great exploration, attention, and enjoyment of EarSketch. The musicians tended to report equal or higher scores across all constructs for TunePad, whereas hybrid students demonstrated the greatest differences between the platforms, indicating that EarSketch promoted greater situational interest among this subgroup of participants. Examination of maintained situational interest revealed that while both coders and musicians favoured TunePad, hybrid students preferred EarSketch. Therefore, while musicians had higher triggered and maintained situational interest in TunePad and hybrid students in EarSketch, coders were more complex. The findings suggest that TunePad's bottom-up, note-based approach was more engaging for students who had a background in music and understood music theory, thus building on their prior music experience and knowledge. Equally, the top-down, audio-based remixing approach within Earsketch was more compatible with users who had less extensive musical knowledge. This study highlights the merits of educators carefully considering the platform that best fits with users' different prior interests and knowledge in order to optimally engage students; thus, enabling optimum benefit from the integration of the musical arts and technology. An enabler within this programme was that music knowledge was not a pre-requisite to participation. The particular features of the platforms were potential barriers to optimum engagement.

There was one study that examined an *informal STEAM education programme that integrated dance and technology*. This study is also discussed in the post-primary literature as it spans both formal and informal settings. Leonard et al. (2021) report on design-based research that explored the impact of an intervention blending dance choreography and computer programming on upper elementary and middle school students (Grade 5-9). Within the intervention, after being introduced to key computational concepts, and exploring the parallels between computer programming and dance choreography, participating students choreographed dances in the physical world and then programmed the corresponding choreography on characters within a virtual platform. This intervention was implemented in various iterations within a range of settings both during-school workshops in two different schools (Two grade 5 dance classes within an arts magnet school: n=41; Grade 6 and 7 graphic communications classes within a local middle school: n=49), an afterschool programme in an elementary school (n=15) and two different summer camps (university-sponsored summer camp: n=11; Women in Science and engineering university sponsored summer camp: n=54). In these settings, the nature of participation varied. For example, after-school programme participants either volunteered or were encouraged to apply if they had a previous interest in either dance or computer programming, whereas for the 'Women in Science and engineering university' sponsored summer camp, participants were already part of a larger camp for middle school girls. Equally, the approach taken to the programme implementation varied, where for example, in schools the authors guest taught the sessions across 11 weeks during their dance class, whereas the after-school programme took places across six weeks.

Data collection used to gauge the impact of participation included pre/post computational thinking test, pre/post biographical surveys, semi-structured interviews, student work and photo/video documentation of performances. Across all contexts, paired-sample t-tests revealed significant improvements in participants' knowledge of computational thinking concepts. There was consistent evidence of a distinct relationship between students' embodied interactions and their expressed learning engagement, where their knowledge and inquiry relied on embodied ways of knowing. These findings suggest that dance supported students in engaging with computer programming, thus acting as an enabler.

Among the relevant informal STEAM research focused on the integration of the performing arts and technology, the enablers and barriers can be summarised in the following table.

Enablers in Performing Arts/Technology - Informal STEAM Education	Barriers in Performing Arts/Technology - Informal STEAM Education
• Students' familiarity and interest in music/dance can act as a motivator • Opportunities to actively create or modify music using STEM knowledge • Integrated STEAM experience where music/dance and STEM understandings are both required and developed • No requirement for musical/dance background or understanding of musical elements • Opportunities to be creative	• Unequal access to STEAM opportunities • Need for specialised support • Limited opportunities to develop understandings of the relevant performing arts • A lack of pre-requisite musical/dance knowledge or experience

Table 38 - Enablers and Barriers Identified in the Performing Arts/Technology Literature within Informal STEAM education

PERFORMING ARTS AND TWO OR MORE STEM DISCIPLINES

While there was an absence of informal education STEAM interventions integrating dramatic art with more than one STEM discipline, there was one study that integrated musical arts and another where dance was the performing arts.

Performing Arts and two or more STEM disciplines	
1	Morton, B.G., Gregorio, J., Rosen, D.S., Vallet, R. and Kim, Y. (2017). *STEAM Education through Music Technology (Evaluation)*. Paper presented at 2017 American Society for Engineering Education (ASEE) Annual Conference & Exposition, Columbus, Ohio.
2	Georgen, C. (2019). *"Can't Nobody Floss Like This!": Exploring Embodied Science Learning in the Third Space*. In Lund, K., Niccolai, G. P., Lavoué, E., Hmelo-Silver, C., Gweon, G., & Baker, M. (Eds.), A Wide Lens: Combining Embodied, Enactive, Extended, and Embedded Learning in Collaborative Settings, 13th International Conference on Computer Supported Collaborative Learning (CSCL) 2019, Volume 1 (pp. 280-287). Lyon, France: International Society of the Learning Sciences.

Table 39 - Evaluation of Informal STEAM Education Literature: Performing Arts (Drama, Music and Dance) and two or more STEM Disciplines

Morton et al.'s (2017) study examined the impact of the Expressive & Creative Interaction Technologies (ExCITe) Centre's week-long *Summer Music Technology* program on participating Philadelphian sophomores and junior high school. The programme, developed in 2006 (http://drexel.edu/excite/engagement/summerMusicTechnology/), was hands-on consisting of a sequence of topics and activities across the week such as loudspeaker design, instrument acoustics, and analog versus digital representations of sound using the custom-developed app Audioworks to visually and aurally explore audio production and modification.

The integrated nature of the programme served as an enabler, where musical, mathematical, scientific and engineering concepts were addressed as appropriate within activities. Students selected a project (from a choice of four) to work on for the week. Students were encouraged to use the engineering design process when completing their project, i.e., iterating and improving their initial prototypes as a result of testing their designs. The programme concluded with students presenting their projects during the project showcase for family and friends on the final day. At this event, students also participated in a technology-infused group musical performance.

The study measured the effect of participation in the summer programme on students' (n=12) perceptions of the programme (surveys after each activity), their learning (projects) as well as their feelings towards STEM fields (surveys at the beginning and end of the week). The findings suggest participants were positive about the programme activities and demonstrated desired understandings through their projects. The pre/post survey comparison evidence that participation positively affected students' interest in mathematics and engineering careers after participating in the summer course (Morton et al. 2017). The students' interest in music alongside the student-led project-based approach served as an enabler within this intervention.

Georgen (2019) reports on a 10-lesson science activity sequence situated in a performing arts centre where *ensemble dance and mixed reality science models* were used to support 35 participants (age 6-8 years) to explore states of matter. In this programme, familiar dance movements were used to represent scientific understanding. During science, the *Science through Technology Enhanced Play (STEP) technology* tracked students' motion and generated a visual representation of the state of matter these particles collectively produced. Through ongoing analysis, children learned to co-ordinate their movement in certain ways to improve models, thus supporting their understanding of the particulate nature of matter. During dance, children learned, practiced, and refined an ensemble dance based on the music and themes of the Disney production ‘Frozen’.

The dance choreography integrated science concepts related to the movement of particles in solid, liquid and gas. The dance was incrementally modified as students’ understandings about the particulate nature of matter developed. While dance communicated aspects of science, attention was equally given to dance criteria e.g. timing, rhythm, presentation. Each week the children engaged in 45 minutes STEP activity facilitated by the research team followed by dance practice choreographed by a camp instructor. Throughout, the research team and dance instructor had regular meetings to ensure optimal integration between the two aspects.

In terms of research methods, interaction analysis was used to understand ways in which children used dance movements to navigate the science concepts and vice versa. Additionally, their science knowledge was measured using multiple choice pre- and post-tests and pre- and post-interviews (n=18). In the interviews, reasoning levels about state change mechanisms were coded using Paik et al. (2004) scheme. Paired t-tests on the pre/post-test suggests that participants’ knowledge of particle behaviour had improved significantly ($p<0.001$). Comparison of pre/post interviews also revealed that participants’ level of reasoning had increased significantly ($p< 0.001$), with the vast majority of students aware that solid particles vibrate, associating the vibration of solid particles with dance-move ‘the floss.’ The findings suggest that dance can be a powerful resource in meaning making, thus acting as an enabler. However, there is further potential for participants to engage in dance creation.

Among the relevant research focused on the integration of the performing arts and two or more STEM disciplines, the enablers and barriers can be summarised in the following table.

Enablers: Performing Arts/ two or more STEM disciplines - Informal STEAM education	Barriers: Performing Arts/ two or more STEM disciplines - Informal STEAM education
• Students' familiarity and interest in music/dance can act as a motivator • Opportunities to develop musical understandings • Opportunities to actively create or modify music using STEM knowledge • Integrated STEAM experience where the musical arts and STEM understandings are required to solve problems • Opportunities to use dance to develop STEM understandings • Opportunities within STEAM activities to develop dance understandings and skills • Opportunities to be creative	• Inadequate access to opportunities • Inadequate access to specialised technologies included • Inadequate specialised support • Absence of pre-requisite musical knowledge/experience • Limited opportunity to develop dance understandings • Limited opportunity to be creative within dance instruction

Table 40 - Enablers and Barriers Identified in the Performing Arts Based/two or more STEM disciplines Literature within Informal STEAM education

CONCLUSIONS AND SYNOPSIS OF KEY ENABLERS AND BARRIERS TO EFFECTIVE INFORMAL STEAM EDUCATION INTERVENTIONS

Across the informal STEAM education interventions explored, a multitude of settings, approaches and foci were represented. Some of the informal STEAM education interventions evidence integration between a single arts subject and a STEM discipline, where the visual arts proved the most popular arts education subject, followed by the dramatic arts whereas science was the most popular STEM discipline, followed by technology. Within these dual-focus STEAM interventions, the STEM disciplines mathematics and engineering were notably absent. There were ample examples of interventions that were more ambitious in integrating the arts with more than one STEM discipline. Again, the visual arts proved a more frequent arts integrator. Regardless of subject integration, it was evident that some of the informal STEAM interventions demonstrated a limited view of the role of the arts within STEAM interventions, where the arts' role was confined to communicating STEM understandings. This is also identified in the post-primary literature. Alternatively, an equally limited approach provided minimal or superficial opportunities to develop arts understandings or to engage in authentic arts experiences. However, there were abundant examples of informal STEAM interventions that modelled the treatment of both the arts and STEM disciplines co-equally. In these interventions, participants had opportunities to develop both their arts and STEM understandings. Generally, these more authentic integrated STEAM interventions promoted opportunities for active engagement in tasks that require creativity, decision making, engagement in an iterative process, collaboration, which in turn triggered educational agency among participants.

However, barriers that impinged genuine STEAM experiences included a lack of time, limited opportunities to develop the requisite understandings/skills, inadequate access to expertise, equal access to interventions/technology, superficial inclusion of the arts, a failure to promote an original response and providing participants with the opportunity to emulate relevant arts/STEM skills prior to creating original responses.

Subsection D: STEAM Education and Teacher Education

It has been repeatedly acknowledged within the interventions that effective professional development of teachers is a key enabler to promote quality STEAM education within the formal sectors. Building on this, a number of articles that focused exclusively on STEAM education initiatives with in-service or pre-service teachers. While this research did not report on the impact on pupil learning or experience, nor did many involve STEAM education interventions, they provided some worthwhile insights into the enablers and barriers for teachers in the implementation of STEAM education.

STEAM Education and Teacher Education	
1	Anisimova, T.I., Sabirova, F.M., & Shatunova, O.V. (2020). Formation of Design and Research Competencies in Future Teachers in the Framework of STEAM Education. *International Journal of Emerging Technologies in Learning, 15*, 204-217.
2	Ben-Horin., Chappell, K., Halstead, J., & Espeland, M. (2017). Designing creative inter-disciplinary science and art interventions in schools: The Case of Write a Science Opera (WASO). *Cogent Education*, 4(1).
3	Belardo, C., Burrows, A., & Dambekalns, L. (2017). Partnering science and art: Pre-service teachers' experiences for use in pre-collegiate classrooms. *Problems of Education in the 21st Century*, 75(3): 215.
4	Echegoyen-Sanz, Y., & Martín-Ezpeleta, A. (2020). The exhibition is just the beginning: Qualitative analysis of creative educational materials prepared by preservice teachers. *Journal of Education Culture and Society*, *11*(2), 297–310.
5	Karppinen, S., Kallunki, V. & Komulainen, K. (2019). Interdisciplinary craft designing and invention pedagogy in teacher education: student teachers creating smart textiles. *International Journal of Technology & Design Education* 29, 57–74.
6	Lee, Y. (2021). Examining the Impact of STEAM Education Reform on Teachers' Perceptions about STEAM in Uzbekistan. *Asia-Pacific Science Education*, *7*(1), 34-63.
7	Martínez-Jiménez, E., Cuadrado-Méndez, F.J., & Gómez-Rey, F. (2019). Bridging the Gap Between Art and Science: An Interdisciplinary Approach to The Teaching of Music and Mathematics with Pre-Service Teachers, Proceedings of the 11th Annual International Conference on Education and New Learning Technologies (EDULEARN19), (pp. 5991-5998).
8	Medina-Jerez, W., Dambekalns, L. & Middleton, K.V. (2012). Art and science education collaboration in a secondary teacher preparation programme. *Research in Science and Technological Education,* 30:2, 209-224.
9	Overton, D.T. and Chatzichristodoulou, M. (2010). The Teaching of Science through the Performing Arts. *Procedia Social and Behavioral Sciences*, 2, 3871–3875.
10	Pool, J., Dittrick, C., & Pool, K (2011). Arts Integration in Teacher Preparation. *Journal for Learning through the Arts,* 7(1).
11	So, H. J., Ryoo, D., Park, H., & Choi, H. (2019). What Constitutes Korean Pre-service Teachers' Competency in STEAM Education: Examining the Multi-functional Structure. *Asia-Pacific Education Researcher*, *28*(1), 47-61.

Table 41 - STEAM Education and Teacher Education

Several research studies cite the need for initial teacher education to better prepare pre-service teachers for teaching STEAM education. Pool et al. (2011) highlight the significant role of initial teacher education in developing the appropriate pedagogical knowledge among prospective teachers, particularly given their limited personal experiences of integrated STEAM practice and the tendency to perceive that their pre-tertiary experiences; which may have been primarily limited to limited integration; as a ‘gold standard’ for their practice. Lee (2021) agrees that knowledge about STEAM education is limited among pre-service teachers and calls for its implementation as a requirement at pre-service level if STEAM education is to lead to effective teaching and learning in schools. Results from a study by Anisimova et al. (2020) also found very low awareness and confidence among pre-service teachers in interdisciplinary teaching. So et al. (2019) assert that the fragmented approach and prevailing disciplinary boundaries within initial teacher education programmes does not prepare pre-service teachers adequately to become competent STEAM education practitioners. Together, these findings suggest that there is a potential problem of teacher readiness to engage with STEAM education initiatives.

Consequently, given teacher educators’ unique position in affecting change to pre-service teachers’ perceptions of appropriate pedagogy, it is essential they model the relevant integrated pedagogical practices within initial teacher education. The opportunity for pre-service teachers to experience STEAM education first-hand challenges them to move beyond the limitations of their prior experiences and develops STEAM competencies (Pool et al. 2011; Medina-Jerez et al. 2012; So et al. 2019). For example, So et al. (2019) suggest that support be offered to pre-service teachers so that they develop positive attitudes toward art and science. This is because positive dispositions can scaffold the development of creative convergence and crucial skills to teach STEAM education effectively. The literature also suggests that STEAM education experiences at initial teacher education stages, can have significant positive impacts on pedagogical learning for pre-service teachers. Karppinen et al. (2019) report on a STEAM education study conducted in primary schools, and describe the positive change in attitude among the pre-service teachers towards integration, use of new pedagogical approaches and greater confidence in interdisciplinary contexts. Echegoyen-Sanz and Martín-Ezpeleta (2020) report that pre-service teachers can benefit from creating STEAM education teaching materials and that this activity enhanced their creativity and served to be formative in their learning about STEAM education. Similarly, Belardo et al. (2017) report on pre-service teachers who participated in a science/art-based integration module prior to leaving initial teacher education. They found that education lecturers can assist student learning in STEAM education by modelling interdisciplinary learning, and in doing so can influence perspectives of pre-service teachers, inspiring them to explore new integrated disciplines in their classrooms. Lecturers that offered integrated modules also enhanced the open-mindedness of the student teachers, to utilise new and varied teaching strategies. In another study, Medina-Jerez et al. (2012) reported that experience of a four-session integrated STEAM activity, where pre-service teachers designed and created a piece of art addressing a core secondary level science concept, positively affected participants' self-ratings of their knowledge and ability to engage their students in interdisciplinary experiences. The study found that with the support of a teacher mentor during school placement, participants sought out collaboration opportunities with colleagues from other disciplines; thus, promoting more meaningful interdisciplinary experiences for their students. Martínez-Jiménez et al. (2019) reported that after engaging in an intervention during initial teacher education, where pre-service teachers who engaged in planning sessions for students integrating mathematics and music, focusing in particular on common concepts such as symmetry, rhythm, participants demonstrated an ability to identify other possible opportunities to teach the two subjects together. The studies suggest that experiencing integrated STEAM education first-hand during initial teacher education can promote these future teachers entering the teaching profession more prepared to collaborate with colleagues to promote meaningful integrated STEAM experiences for their students (Medina-Jerez et al. 2012).

Nonetheless, several studies highlighted the challenges of implementing interdisciplinary approaches at initial teacher education. Ben-Horin et al. (2017) conducted a STEAM education project with in-service and pre-service teachers and found that STEAM education teaching is extremely resource-intensive, requiring significant collaboration, time, and pre-project planning. They also found that fewer learning outcomes from the science curriculum were taught using a STEAM approach when compared with traditional teaching. They suggest that these findings may have implications for the design of curriculum, to accommodate the complexity and resource-heavy nature of interdisciplinary teaching, in STEAM education. In addition, pre-service teachers' beliefs can be resistant to change. For example, in Overton and Chatzichristodoulou's (2010) study where pre-service teachers explore science concepts through the performing arts, participants did not envisage using this approach in their future practice.

SUMMARY CONCLUSIONS OF KEY ENABLERS AND BARRIERS TO EFFECTIVE STEAM INTERVENTIONS

Analysis of the selected studies illuminate aspects of the STEAM education landscape. Although several rigorous studies have been conducted at the primary level, few studies in the post-primary and informal sectors can be categorized as highly rigorous empirical research, with many empirical studies featuring a lack of randomization, control groups and limited statistical evaluation of data. This is understandable given that STEAM education is new and there is still a level of ambiguity among practitioners and researchers as to what effective STEAM education entails. What is discussed in the preceding sections represents the most relevant and efficacious studies available at this time. Additionally, many larger studies reported that their research was supported by funding from external sources. These external sources included grants from governmental agencies, public and private companies and from educational institutions. Therefore, the researchers recommend considering how these external influences could potentially have impacted motivation for and direction of research, accessibility of resources, and reporting of findings.

RESEARCH APPROACH

There is a dominance of mixed methods studies, particularly at post-primary level and within informal education. The prevalence of this pragmatic approach may be due to flexibility in gathering qualitative and quantitative data. At times though, it could be argued that this approach was not the most suitable choice for the research questions posed. Some of the most persuasive arguments came from qualitative studies that focused on the experiences of learners, using student voice and rich description. Equally, the measures used to evaluate interventions could have been re-considered in some cases, in terms of their appropriateness, in instances where studies used standardised tests or extant instruments designed for a different purpose, to measure improvements or changes in students' learning.

Common enablers and barriers across the sectors

The enablers for effective STEAM education within formal education settings were consistent across the studies, with the importance of teacher professional development, an interdisciplinary team, connections with stakeholders inside and outside the school, adaptability of the formal curricular structures to facilitate projects, a constructivist approach to teaching and learning, and meaningful and equal integration of the arts-based elements of the intervention. Additionally, in primary education settings, play-based approaches were identified as an effective approach for successful STEAM integration, as was embracing young children's natural curiosity. Within informal settings, enablers included access to relevant courses, technology, expertise, promotion of student-led learning thus promoting agency, creativity and the opportunity to develop both arts and STEM understandings. In all settings, collaborative learning approaches and group-work constituted the structure of the learning environment, with the exception of some individual visual arts interventions where a child created artwork personal to them, their family or their community. Despite this individual focus, elements of cooperative learning were implemented at stages in the intervention. Likewise, barriers to effective implementation commonly cited within both formal and informal education settings included an over-focus on the STEM discipline at the expense of the arts, a need to enhance self-efficacy and expertise of teachers and leaders implementing STEAM, limited time and resources for projects within pressured formal curricula, and a unified and mutual understanding of STEAM education. In the formal education setting, there was also a lack of leadership or practitioner support for STEAM education.

PEDAGOGICAL APPROACH AND LEARNER AGENCY

It is worth noting that several studies across the sectors, but particularly at early years and primary level and many informal education interventions, emphasise the importance of teachers using a range of communication pathways rather than a didactic style of teaching. Research suggests that when the trajectory of learning is steered by student questions such student-directed learning generates a positive learning legacy. A significant number of studies approached student learning from the child's own personally constructed experiences and activities. For example, there was value in the learner creating a personally relevant piece of artwork, as this was found to increase children's empowerment. Nonetheless, it was broadly agreed that finding opportunities for natural integration and facilitating learners to identify points of intersection between the arts and science can be challenging. Therefore, input from professionals in the performing arts and teachers stimulates the learner's creative imagination, enhances commitment and mitigates the demands on educators to be 'experts' in an expanding number of areas. This suggests an argument for contextually appropriate guided interactions rather than an exclusive reliance on spontaneous or child-led approaches. Appropriate guidance and support also assisted with negotiations between student peers and educators over positions of authoring and power. It was widely acknowledged that approaches where the art is driving the STEM discipline, rather than the other way around are less readily understood. Some studies point to cultural perspectives to alleviate this challenge suggesting that drawing on ideas and values that are of personal, family or community consequence, whilst exploring STEAM using real-world problems located within students' social, cultural and ecological contexts, has huge learning and relational potential for students and teachers.

ARTS-BASED AND STEM INTEGRATION

Across all sectors, most of the selected studies focused on one STEM discipline with a specific arts-based domain e.g., music or drama. There was an element of consistency noted across the integration of disciplines within the sectors. For example, at the early years and primary level most of the arts-science integration studies integrated science with the visual arts. In contrast, at post-primary level most of the science studies integrated with the dramatic arts and there were few studies integrating visual arts with any of the STEM disciplines. Within the informal STEAM education context, the integration of science with the visual arts and the dramatic arts were equally prevalent. A few studies on makerspaces and engineering and the arts were discussed. In some cases, the term arts 'infused' or arts 'informed' was used to fit the project into the domain of STEAM education, but in many cases the integration of the arts, as the terms suggest was limited. At post-primary level, the integration of mathematics with music was most prominent. However, at the early years and primary level there was an even spread of visual arts-mathematics integration and performing arts-mathematics integration. Mathematics-arts integration was notably absent within the informal STEAM education contexts. Technology was integrated most often with the musical arts and/or dance at both the post-primary and informal sectors and with drama at the early years and primary level. In comparison to the formal education sectors, particularly at post-primary level, there was more evidence of integration of the arts with more than one STEM discipline in informal STEAM education interventions.

Across both the formal education and informal STEAM education interventions, in some cases the integration of the arts was superficial or tended to prioritise STEM knowledge; demonstrated a one-sided instrumental approach. In such instances, there was further potential to thread the arts throughout the learning process; thus, developing both arts and STEM knowledge and skills. However, a positive outcome within the informal STEAM education studies was that there were a number of interventions that promoted the concomitant development of students' arts and STEM understandings and dispositions; that is the arts and STEM were valued and engaged co-equally.

The review of intervention studies at post-primary highlights the need for a broadening of the domains of integration within STEM and across the arts. That said, studies that tried to do too much, too soon, such as those that attempted to implement a whole school approach to STEAM, were counterproductive in some cases. Within the informal STEAM education landscape, there was a notable imbalance between the arts and STEM subjects evident within interventions, where, as mentioned, STEM subjects like mathematics received little explicit attention. Similarly, at the early years and primary level, relatively few studies explored the potential for music integration. This review highlights that the literature focus related to STEAM education is at an exploratory and early phase. There is significant scope for innovation and creativity regarding research focus, design, and implementation of STEAM education interventions.

Importantly, some studies discussed the transition from STEM to STEAM via a whole school approach (see Hunter-Doniger and Sydow, 2016), with the central focus of the STEM to STEAM intervention being to infuse the arts successfully. This highlighted additional noteworthy barriers that had not come to light in the interventions evaluated. In some cases, teachers articulated a significant lack of time to work with both the arts and STEM subjects. In addition, disruptive behaviour among students in STEAM education lessons and how to assess the arts were cited as challenges leading to significant resistance from teachers to implement STEAM education within their classes. Therefore, enforcing a STEAM approach may damage self-efficacy and have a negative impact on teaching and learning if practitioners are not committed and have a belief in the value of the STEAM curriculum. These findings highlight that trying to do too much too soon from a whole school perspective is not wise. Indeed, many of the successful interventions in formal education focused on making use of the natural connections between the arts and STEM disciplines. In addition to these points is an important caveat that was mentioned in a few studies but given the positive dispositions towards the exploration of STEAM education in the research reviewed, was not discussed in depth. This is the important consideration of the unique and specific role, status and positioning of discrete STEM and indeed arts knowledge, skills and values inherent in each discipline. Further discussion and research studies are required to elicit how foundation epistemologies inherent in discrete disciplines do not become lost in the assimilation and integration of transdisciplinary initiatives within STEAM education.

CULTURAL PERSPECTIVES AND STEAM EDUCATION

Many of the studies included a research question, which specifically addressed a cultural concern or question around representation and inclusivity within STEM education. This is important as gender, race and social class can intersect to create a persistent hegemonic STEM landscape in schools and in society. Few studies focused solely on critical perspectives usually including a measurement on learning, attitude or interest in STEM/STEAM education.

AREAS FOR FURTHER STEAM EDUCATION RESEARCH

Kang’s (2019) STEAM education review paper documented several noteworthy enablers and barriers to effective STEAM interventions at post-primary level. The significant role of professional development, as previously mentioned, in enhancing teacher confidence as STEAM educators is highlighted. The review also calls for more research focused specifically on connections between teacher perceptions of STEAM, and their practice while teaching students. In fact, it is true that assessment of STEAM learning is a domain requiring significant consideration. Few studies made any reference to the use or development of models of formative or summative assessment suitable to assess learning of associated knowledge, skills or attitudes, beyond the research instrument employed for the purposes of answering the research question. It could be argued that until there is greater uniformity and confidence among teachers’ perceptions of STEAM education, there will be challenges with pedagogies and assessment. This literature review did not identify significant or dominant mediating factors for successful STEAM education interventions and concludes that further studies are required to assess contextual and other variables that may play a functional role in such student learning. This highlights the difficulties associated with implementing and indeed researching effective interventions in STEAM education.

Section 4: Moving Forward

This systematic review of the literature identifies evidence-based interventions that promote the inclusion of arts as an integral part of STEAM learning (Terms of Reference 1) and analysed international sector-wide policies or practices that promote STEAM learning (Terms of Reference 2). Furthermore, it has evaluated how learning in the domains of STEM and the arts are mutually beneficial within formal and informal settings and identified any limitations therein (Terms of Reference 3). The report identifies some of the risks and challenges in promoting STEAM education policies and practices in terms of possible unintended consequences or collateral impact (Terms of Reference 4). Further work on ToR4, will be possible over the coming years; the synthesis will require more extensive investigation of policy contexts, curriculum design and assessment structures, teacher qualifications and out-of-school-partnerships.

The evaluation of interventions in STEAM across early childhood, primary, post-primary and informal educational settings has resulted in the identification of a range of enablers and barriers to the implementation of effective STEAM education. Subsequent review of the relevant literature focusing on initial teacher STEAM education alongside other research that explores STEAM education more generally (Clapp and Jimenez, 2016; Johnson-Green et al., 2020; Liu et al., 2021) identify additional macro enablers and barriers to the promotion of STEAM education. Below we summarise the identified enablers and barriers from both contexts separately:

Macro Barriers to STEAM Education (from evaluated interventions)

FOR MEANINGFUL INTEGRATED STEAM EDUCATION

- Absence of a shared understanding regarding the meaning of integrated STEAM education
- A lack of understanding amongst some teachers regarding how to teach integrated STEAM
- An absence of opportunity to collaborate with colleagues across the arts and STEM disciplines

- Limited, poor or a lack of initial teacher education and continuous professional development that supports the implementation of authentic STEAM education
- Low interest in the arts at school level or limited investment in STEAM education
- Over focus on STEM at the expense of the arts
- Superficial treatment of the arts within STEAM education contexts
- Low levels of self-efficacy and expertise of some teachers and leaders
- Limited time and resources within pressurised formal curricula and informal courses
- Lack of leadership at school level leading to unsupported or frustrated novice STEAM practitioners
- Attempting to do too much too soon at the school level

FOR STUDENT LEARNING

- Limited opportunity to engage with the arts
- Didactic pedagogical approach to teaching the arts and STEM subjects
- Closed activities that fail to promote originality, creativity, and agency
- Lack of opportunities to develop both arts and STEM understandings

Additional Macro Barriers to STEAM Education (from theoretical studies)

FOR MEANINGFUL INTEGRATED STEAM EDUCATION

- Curricula are already overloaded
- Limited opportunities for experimentation
- A lack of policy focus on the benefits and characteristics of integrated STEAM education
- Multiple diverse interpretations of what constitutes arts education within integrated STEAM education

- An absence of reference to integrated STEAM education within initial teacher education
- Limited ability to measure the outcomes of integrated STEAM education
- Over focus on meeting the requirements of state examinations at post-primary level

Macro Enablers to STEAM Education (from evaluated interventions)

FOR MEANINGFUL INTEGRATED STEAM EDUCATION

- Formal opportunities for collaboration and co-construction of projects, within and between sectors, institutions and organisations to bring the relevant expertise together
- Access to quality initial teacher education and teacher professional development prior to and during engagement in STEAM education
- Shared understanding of STEAM education from school and local community resources and expertise in the design and implementation of STEAM education initiatives
- The development of inter-disciplinary teams of arts and STEM experts
- Connections between all stakeholders
- Effective leadership to support stakeholders implementing or planning STEAM education initiatives
- Developing realistic, manageable and feasible goals in the early stages of STEAM education development
- Adaptability of formal curriculum structures to facilitate STEAM education

FOR STUDENT LEARNING

- Access to high quality integrated STEAM Education initiatives
- Opportunities to develop both arts and STEM understandings equally

- Constructivist approaches to learning and a learner centred focus
- Access to relevant expertise in the arts and STEM disciplines
- Authentic and meaningful engagement of the arts in all STEAM interventions
- Opportunities to engage in projects that promote agency, creativity and student voice
- The inclusion of cultural pedagogies in STEAM education

Additional Macro Enablers to STEAM Education (from theoretical studies)

FOR MEANINGFUL INTEGRATED STEAM EDUCATION

- The development of policy referring to the definition of what constitutes STEAM learning and role of STEAM education
- A consistent interpretation of the arts within STEAM education
- The inclusion of the arts education community in conversations regarding what constitutes STEAM education and what it should entail in practice
- The design of high-quality curricular materials
- The development of assessment strategies to gauge STEAM learning
- The prioritisation of quality practice over considerations of scale of intervention
- Providing teachers autonomy to incorporate integrated STEAM into their curriculum time

FOR STUDENT LEARNING

- STEAM integration that incorporates quality arts education
- Arts leading rather than book-ending integrated STEAM learning

Concluding Remarks

This report highlights unequivocally that STEAM education has transformative potential for learners, in their pursuit of knowledge, skills and dispositions and for their essential participation and engagement as global citizens of the 21st century.

Nonetheless, the STEAM education landscape is currently in a state of flux due to being in an early exploration phase and still not fully assimilated in terms of a common purpose, vision, and the implementation of an agreed and equitable pedagogy. However, with due regard to the enablers identified in this report and with adequate acknowledgement of the need to address and manage barriers cited as impediments to effective STEAM intervention, the STEAM education trajectory holds endless possibilities. The emergence of educational advancement measures requires re-assessment at developmental nodes, to achieve transformative change in systems of teaching and learning. This report captures one such juncture, in the hope that its contents offer scope and evidence-based critique for those in a position to engender and support educational transformation.

References

Adjapong, E.S. and Emdin, C., (2015). Rethinking Pedagogy in Urban Spaces: Implementing Hip-Hop Pedagogy in the Urban Science Classroom. *Journal of Urban Learning, Teaching, and Research,* 11: 66-77.

Ahn, J., & Kwon, N. (2017). An Analysis on STEAM Education Teaching and Learning Program on Technology and Engineering. *Journal of the Korean Association for Science Education, 33*(4), 708-717.

Allina, B. (2018) The development of STEAM educational policy to promote student creativity and social empowerment. *Arts Education Policy Review, 119*:2, 77-87, DOI: 10.1080/10632913.2017.1296392.

Andrikopoulou, E., & Koutrouba, K. (2019). Promoting Mindfulness about the Environment through the Use of Drama in the Primary Classroom: Greek Teachers' Views and Attitudes. *Education Sciences*. 9(1), 22. https://doi.org/10.3390/educsci9010022

Anisimova, T.I., Sabirova, F.M., & Shatunova, O.V. (2020). Formation of Design and Research Competencies in Future Teachers in the Framework of STEAM Education. *International Journal of Emerging Technologies in Learning*, 15, 204-217.

Ariba, O., & Luneta, K. (2018). Nurturing Creativity in Early Years' Mathematics via Art-Integrated Mathematics Lessons. *The International Journal of Early Childhood Learning*. 25 (2), 31-48. https://doi.org/10.18848/2327-7939/CGP/v25i02/31-48

Australian Curriculum (2021), F-10 curriculum (Version 8.4), accessed 19 Oct 2021. Available: https://www.australiancurriculum.edu.au/f-10-curriculum/

Bassachs, M., Cañabate, D., Nogué, L., Serra, T., Bubnys, R. and Colomer, J., (2020). Fostering Critical Reflection in Primary Education through STEAM Approaches. *Education Sciences, 10*(12), 384-398. https://doi.org/10.3390/educsci10120384

Belardo, C., Burrows, A., & Dambekalns, L. (2017). Partnering science and art: Pre-service teachers' experiences for use in pre-collegiate classrooms. *Problems of Education in the 21st Century,* 75(3): 215.

Ben-Horin., Chappell, K., Halstead, J., & Espeland, M. | (2017). Designing creative inter-disciplinary science and art interventions in schools: The Case of Write a Science Opera (WASO), *Cogent Education*, 4(1), doi.10.1080/2331186X.2017.1376926.

Boland, A., Cherry, G., & Dickson, R. (2017). *Doing a Systematic Review: A Student's Guide (2nd ed.). Thousand Oaks, CA: SAGE.*

Brezovnik, A. (2015). The Benefits of Fine Art Integration into Mathematics in Primary School. *CEPS Journal: Center for Educational Policy Studies Journal*. 5(3), 11-32. https://doi.org/10.26529/cepsj.125

Burke, L., Wessels, A. and McAvella, A., (2018). Using theater and drama to expose and expand the epistemic insights of youth regarding the nature of science. *Research in Science Education,* 48(6):1151-1169.

Caiman, C., Jakobson, B. (2019). The Role of Art Practice in Elementary School Science. *Science & Education* 28(1-2), 153–175. https://doi.org/10.1007/s11191-019-00036-2

Champion, D.N., Tucker-Raymond, E., Millner, A., Gravel, B., Wright, C.G., Likely, R., Allen-Handy, A. and Dandridge, T.M., 2020. (Designing for) learning computational STEM and arts integration in culturally sustaining learning ecologies. *Information and Learning Sciences,* 121(9-10): 785-804

Chapman SJ, Shelton B, Mahmood H, Fitzgerald JE, Harrison EM, Bhangu A. (2014). Discontinuation and non-publication of surgical randomised controlled trials: observational study. *BMJ*; 349: g6870. https://doi.org/10.1136/bmj.g6870

Choi, J.H. & Hwang B.K. (2017). The Concepts, Strategies and Application of STEAM Education in South Korea. *Conference Proceedings of the 7th World Engineering Education Forum (WEEF)*. 466-469.

Chow, J. & Eckholm, E. (2018). Do published studies yield larger effect sizes than unpublished studies in education and special education? A meta-review. *Educational Psychology Review 30*(3), 727–744.

Clapp, E.P. and Jimenez, R.L. (2016). Implementing STEAM in Maker-Centred Learning, *Psychology of Aesthetics, Creativity, and the Arts*, 10(4): 481-491.

Coleman, C., & Davies, K. (2018). Striking gold: Introducing Drama-Maths. *Teachers and Curriculum* 18(1), 9-18. http://dx.doi.org/10.15663/tandc.v18i1.324

Conradty, C., Sotiriou, S.A. and Bogner, F.X., (2020). How creativity in STEAM modules intervenes with self-efficacy and motivation. *Education Sciences*, 10(3):70.

DeJarnette, N. (2018). Early Childhood Steam: Reflections from a Year of Steam Initiatives Implemented in a High-Needs Primary School. *Education, 139(2), 96-112.*

Dell'Ebra, M. (2019a). *Preparing Students for Learning, Work and Life through STEAM Education.* Policy Brief, Sept 2019. Arts Education Partnership. Education Commission of the States.

Dell'Ebra, M. (2019b). *Policy Considerations for STEAM Education*. Policy Brief, March 2019. Arts Education Partnership. Education Commission of the States.

Department of Education and Science (2017). *STEM Education Policy Statement 2017–2026*, available online: https://www.education.ie/en/The-Education-System/STEM-Education-Policy/stem-education-policy-statement-2017-2026-.pdf

Department for Education, UK (2014). *The National Curriculum in England Framework Document.* Accessed 19 Oct 2021. Available: *https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/381344/Master_final_national_curriculum_28_Nov.pdf*

Devaney, K. (2019). 'Waiting for the wow factor': Perspectives on computer technology in classroom composing. *Journal of Music, Technology & Education*, 12(2): 121-139.

Dhanapal, S., Kanapathy, R., & Mastan, J. (2014). A Study to Understand the Role of Visual Arts in the Teaching and Learning of Science. *Asia-Pacific Forum on Science Learning and Teaching*. 15(2), 12.

Dixon, C., Schimpf, C.T., and Hsi, S. (2019). Beyond Trial and Error: Iteration-to-learn using computational papercraft in a STEAM camp for girls. *Paper presented at 2019 ASEE Annual Conference & Exposition,* Tampa, Florida. 10.18260/1-2—32153

Duman, B. & Özçelik, C. (2018). The Effect of the Creative Drama-supported Problem-based Learning Approach on the Self-efficacy Ability in Geometry. *Universal Journal of Educational Research,* 6(12), 2918-2924. doi:10.13189/ujer.2018.061227.

Echegoyen-Sanz, Y., & Martín-Ezpeleta, A. (2020). The exhibition is just the beginning: Qualitative analysis of creative educational materials prepared by preservice teachers*. Journal of Education Culture and Society,* 11(2), 297–310. https://doi.org/10.15503/jecs2020.2.297.310.

Education Commission of the States (2019). *STEAM Infographic.* Available: https://www.ecs.org/steam-infographic/

Edwards P, Clarke M, DiGuiseppi C, Pratap S, Roberts I, Wentz R. (2002). Identification of randomized controlled trials in systematic reviews: accuracy and reliability of screening records. *Statistics in Medicine*, 21: 1635-1640.

Engelman, S., Magerko, B., McKlin, T., Miller, M., Edwards, D. and Freeman, J., (2017), March. Creativity in authentic STEAM education with EarSketch. *In Proceedings of the 2017 ACM SIGCSE Technical Symposium on Computer Science Education* (183-188).

Eurydice (2016), *The National plan for digital school (PNSD)*, Accessed 18 Oct 2021. Available: file:///C:/Users/User/Downloads/eurydice_-_pnational_reforms_related_to_transversal_skills_and_employabilityp_-_2017-10-09%20(1).pdf

Eurydice (2021). *Romania- Ongoing reforms and policy development*, September, 2021. Accessed 18 Oct 2021, available: https://eacea.ec.europa.eu/national-policies/eurydice/content/ongoing-reforms-and-policy-developments-56_en

Fink, A. (2019). *Conducting research literature reviews: From the internet to paper (5th ed.).* Thousand Oaks, CA: SAGE.

Freeman, J., Magerko, B., Edwards, D., Miller, M., Moore, R. and Xambó, A., (2016). Using earsketch to broaden participation in computing and music. *13th sound and music computing conference*, Hamburg, Germany, 31 August-3 September

Garrett, R., Dawson, K., Meiners, J., & Wrench, A. (2018). Creative and Body-based Learning: Redesigning Pedagogies in Mathematics. *Journal for Learning through the Arts*, 14(1), 1-20. http://dx.doi.org/10.21977/D914136982

Georgen, C. (2019). “Can’t Nobody Floss Like This!”: Exploring Embodied Science Learning in the Third Space. In Lund, K., Niccolai, G. P., Lavoué, E., Hmelo-Silver, C., Gweon, G., & Baker, M. (Eds.), A Wide Lens: Combining Embodied, Enactive, Extended, and Embedded Learning in Collaborative Settings, *13th International Conference on Computer Supported Collaborative Learning (CSCL)* 2019, Volume 1 (pp. 280-287). Lyon, France: *International Society of the Learning Sciences.*

Gershon, W. S., and Ben-Horin, O. (2014). Deepening inquiry: What processes of making music can teach us about creativity and ontology for inquiry-based science education. *International Journal of Education & the Arts*, 15(19): 1-38.

Gough, D., Oliver, S., & Thomas, J. (2017). *An introduction to systematic reviews (2nd ed.).* Thousand Oaks, CA: SAGE.

Graham, N.J., & Brouillette, L. (2016). Using Arts Integration to Make Science Learning Memorable in the Upper Elementary Grades: A Quasi-Experimental Study. *Journal for Learning through the Arts,* 12(1), 1-17. doi:10.21977/D912133442

Grzybowski, D.M., and Dixon, K. (2016). RTP Design as the Practice of Probability: Engaging Adolescent Girls in Art-Infused Engineering, *ASEE annual conference and exposition*, New Orleans, June 29th, 2016.

Hardiman, M & Rinne, L. & Yarmolinskaya, J. (2014). The Effects of Arts Integration on Long-Term Retention of Academic Content. *Mind, Brain, and Education*. 8(3), 144-148. https://doi.org/10.1111/mbe.12053

Hardiman, M.M., John Bull, R.M., & Carran, D.T. (2017). T*he Effects of Arts-Integrated Instruction on Students' Memory for Science Content: Results from a Randomized Control Trial Study.* Paper presented at the annual meeting of the American Educational Research Association, San Antonio, Texas.

Hart, C. (2017). *Doing a literature review: Releasing the research imagination (2nd ed.).* Thousand Oaks, CA: SAGE.

Hendrix, R., Eick, C.J., & Shannon, D.M. (2012). The Integration of Creative Drama in an Inquiry-Based Elementary Program: The Effect on Student Attitude and Conceptual Learning. *Journal of Science Teacher Education,* 23(7), 823-846. https://doi.org/10.1007/s10972-012-9292-1

Heras, M., Ruiz-Mallén, I., and Sandrine Gallois, S. (2020) Staging science with young people: bringing science closer to students through stand-up comedy, *International Journal of Science Education,* 42(12): 1968-1987.

Heuling, L.S., (2021). Promoting student interest in science: The impact of a science theatre project. *LUMAT Special Issue*, 9(2): 63–81.

Heyvaert, M., Hannes, K., & Onghena, P. (2016). *Using mixed methods research synthesis for literature reviews.* Thousand Oaks, CA: SAGE.

Hong, O. (2017). STEAM Education in Korea: Current Policies and Future Directions. *Science and Technology Trends Policy Trajectories and Initiatives in STEM Education.* 92-102.

Hunter-Doniger, T. (2020). Seeing the forest through the trees: at the intersection of Forest Kindergartens and art-based environmental education, *Journal of Adventure Education and Outdoor Learning.* DOI: 10.1080/14729679.2020.1771388

Hunter-Doniger, T. (2021) Early Childhood STEAM Education: The Joy of Creativity, Autonomy, and Play. *Art Education,* 74(4), 22-27. doi:10.1080/00043125.2021.1905419.

Hunter-Doniger, T. and Sydow, L., (2016). A journey from STEM to STEAM: A middle school case study. *The Clearing House*: *A Journal of Educational Strategies, Issues and Ideas*, 89(45): 159-166.

Jakobson, B. & Wickman, P. (2015). What Difference Does Art Make in Science? A Comparative Study of Meaning-Making at Elementary School. *Interchange: A Quarterly Review of Education,* 46(4), 323-343. doi:10.1007/s10780-015-9262-6

Jho, H., Hong, O., & Song, J. (2016). An analysis of STEM/STEAM teacher education in Korea with a case study of two schools from a community of practice perspective. *Eurasia Journal of Mathematics, Science & Technology Education*, 12(7), 1843-1862.

Johnson-Green, E., Lee, C., & Flannery, M. (2020). A Musical Perspective on STEM: Evaluating the EcoSonic Playground Project from a Coequal STEAM Integration Standpoint. *International Journal of Education & the Arts*, *21*(14). http://doi.org/10.26209/ijea21n14.

Kang, N.-H. (2019). "A review of the effect of integrated STEM or STEAM (science, technology, engineering, arts, and mathematics) education in South Korea." *Asia-Pacific Science Education,* 5(1): 1-22.

Kang, N., Yu, J., Byun, S., Im, S., Oh, K., Jeong, J., & Lee, N. (2017). *The effect of STEAM Projects: Year 2016 Analysis*. Seoul: KOFAC.

Kaplan, M. (2017). Orchestrating a new approach to learning. *Phi Delta Kappan.* 98(7), 23–28. doi: 10.1177/0031721717702627.

Karppinen, S., Kallunki, V. & Komulainen, K. (2019). Interdisciplinary craft designing and invention pedagogy in teacher education: student teachers creating smart textiles. *International Journal of Technology & Design Education* 29, 57–74 https://doi.org/10.1007/s10798-017-9436-x

Kim, Y., & Kim, J. (2017). Analysis of status about theses and articles related to domestic STEAM education. *Journal of the Korean Institute of Industrial Educators*, 42(2), 140-159.

Kirkpatrick D.L. & Kirkpatrick J.D. (2006). *Evaluating training programs: The four levels.* 3rd ed. San Francisco: Berrett-Koehler Publication.

Klein, J.L., Gray, P., Zhbanova, K.S. and Rule, A.C. (2015). Upper Elementary Students Creatively Learn Scientific Features of Animal Skulls by Making Movable Books. *Curriculum & Instruction Faculty Publications*. 13. https://scholarworks.uni.edu/ci_facpub/13.

Klopp, T.J., Rule, A.C., Schneider, J.S., & Boody, R.M. (2014). Computer Technology-Integrated Projects Should not Supplant Craft Projects in Science Education, *International Journal of Science Education*, 36(5), 865-886, doi:10.1080/09500693.2013.829927

Kolovou, M., and Kim, N (2020). Effects of implementing an integrative drama-inquiry learning model in a science classroom. *The Journal of Educational Research*, 113(3): 191-203.

Korea Foundation for the Advancement of Science and Creativity (2016). *Introduction to STEAM education*. Seoul: KOFAC.

Kukreti., A., Jackson, H., Steimle, J., and G. L. Ogden, (2014). Math projects integrate engineering design & artistic creativity. *IEEE Integrated STEM Education Conference*, 1-5, doi: 10.1109/ISECon.2014.6891031.

Kuznetsov, S., Trutoiu, L.C., Kute, C., Howley, I., Siewiorek, D. and Paulos, E. (2011). Breaking Boundaries: Strategies for Mentoring through Textile Computing Workshops, In CHI 2011- 29th *Annual CHI Conference on Human Factors in Computing Systems, Conference Proceedings and Extended Abstracts* ([pp. 2957-2966). https://doi.org/10.1145/1978942.1979380.

Lagerlöf, P., Wallerstedt, C., & Pramling, N. (2013). Engaging children's participation in and around a new music technology through playful framing. *International Journal of Early Years Education*. 21(4), 325-335. https://doi.org/10.1080/09669760.2013.867170

Leandro, C., Monteiro, E., & Melo, F. (2018). Interdisciplinary working practices: can creative dance improve math? *Research in Dance Educatio*n. 19(1), 74-90. doi:10.1080/14647893.2017.1354838.

Lee, Y. (2021). Examining the Impact of STEAM Education Reform on Teachers' Perceptions about STEAM in Uzbekistan. *Asia-Pacific Science Education*, 7(1), 34-63. doi: https://doi.org/10.1163/23641177-bja10025

Leinonen, T., Virnes, M., Hietala, I., & Brinck, J. (2020). 3D Printing in the Wild: Adopting Digital Fabrication in Elementary School Education. *International Journal of Art and Design Education,* 39(3), 600-615. https://doi.org/10.1111/jade.12310

Leonard, A., Daily, S., Jörg, S., and Babu, S. (2021) Coding moves: Design and research of teaching computational thinking through dance choreography and virtual interactions, *Journal of Research on Technology in Education*, 53(2):159-177.

Leonard, AE., Dsouza, N., Babu, SV., Daily, SB; Jörg, S., Waddell, C., Parmar, D., Gundersen, K., Gestring, J., & Boggs, K. (2015). Embodying and Programming a Constellation of Multimodal Literacy Practices: Computational Thinking, Creative Movement, Biology, & Virtual Environment Interactions. *Journal of Language and Literacy Education,* 11(2), 64-93.

Li, Y., Wang, K., Xiao, Y. et al. (2020). Research and trends in STEM education: a systematic review of journal publications. *International Journal of STEM Education, 7*, (11). https://doi.org/10.1186/s40594-020-00207-6

Lindberg L., Fields DA., and Kafai YB. (2020) STEAM Maker Education: Conceal/Reveal of Personal, Artistic and Computational Dimensions in High School Student Projects. *Frontiers in Education,* 5(51): 22-41.

Liu, C.-Y., Wu, C.-J., Chien, Y.-H., Tzeng, S.-Y., & Kuo, H.-C. (2021). Examining the Quality of Art in STEAM Learning Activities. *Psychology of Aesthetics, Creativity, and the Arts*. Advance online publication. http://dx.doi.org/10.1037/aca0000404

MacDonald, A., Wise, K., Tregloan, K., Fountain, W., Wallis, L. and Holmstrom, N. (2020). Designing STEAM education: Fostering relationality through design-led disruption. *International Journal of Art & Design Education*, 39(1), 227-241.

Magerko, B., Freeman, J., Mcklin, T., Reilly, M., Livingston, E., Mccoid, S., & Crews-Brown, A. (2016). "EarSketch: A STEAM-Based Approach for Underrepresented Populations in High School Computer Science Education". *ACM Transactions on Computing Education* (TOCE), 16(4): 14.

Maharaj-Sharma, R. (2018). Drama in Science Teaching – An example from Trinidad and Tobago. *The Electronic Journal of Science Education,* 22(4), 19-34.

Malone, K. M., Tiarani, V., Irving. K. E., Kajfez, R., Lin, H., Giasi, T. and Edmiston, B. W. (2018). Engineering Design Challenges in Early Childhood Education: Effects on Student Cognition and Interest. *European Journal of STEM Education,* 3(3), 11. https://doi.org/10.20897/ejsteme/3871

Martínez-Jiménez, E., Cuadrado-Méndez, F.J., & Gómez-Rey, F. (2019). Bridging the Gap Between Art And Science: An Interdisciplinary Approach to The Teaching of Music and Mathematics with Pre-Service Teachers, *Proceedings of the 11th Annual International Conference on Education and New Learning Technologies* (EDULEARN19), (pp. 5991-5998). http://dx.doi.org/10.21125/edulearn.2019.1444.

McGregor, D. (2014). Chronicling innovative learning in primary classrooms: Conceptualizing a theatrical pedagogy to successfully engage young children learning science. *Pedagogies: An International Journal,* 9(3), 216-232. doi:10.1080/1554480X.2014.899544.

McKenzie, J.E., Brennan, S.E., Ryan, R.E., Thomson, H.J., Johnston, R.V. & Thomas, J. (2019). “Defining the criteria for including studies and how they will be grouped for the synthesis” (pages 33-63). In Higgins JPT, Thomas J, Chandler J, Cumpston M, Li T, Page MJ, Welch VA (2019). *Cochrane Handbook for Systematic Reviews of Interventions*. 2nd Edition. Chichester (UK): John Wiley & Sons.

McKlin, T., Magerko, B., Lee, T., Wanzer, D., Edwards, D., Freeman, J. (2018). Authenticity and Personal Creativity: How EarSketch Affects Student Persistence. *Proceedings of the 49th ACM Technical Symposium on Computer Science Education.* SIGCSE’18, February 21-24, Baltimore

McKlin, T., McCall, L., Lee, T., Magerko, B., Horn, M. and Freeman, J. (2021). Leveraging Prior Computing and Music Experience for Situational Interest Formation. In SIGCSE 2021 - Proceedings of the 52nd ACM Technical Symposium on Computer Science Education (pp. 928-933). (SIGCSE 2021 - *Proceedings of the 52nd ACM Technical Symposium on Computer Science Education). Association for Computing Machinery, Inc.* https://doi.org/10.1145/3408877.3432431.

Medina-Jerez, W., Dambekalns, L. & Middleton, K.V. (2012). Art and science education collaboration in a secondary teacher preparation programme*, Research in Science and Technological Education,* 30:2, 209-224, https://doi.org/10.1080/02635143.2012.698603

Mejias, S., Thompson, N.,, Sedas, R.M.,, Rosin, M.,, Soep, E., Peppler, K., Roche, J., Wong, J.,, Hurley, M., Bell, P., and Bevan, B. (2021). *The trouble with STEAM and why we use it anyway. Science Education, 105*(2). 209 - 231. ISSN 0036-8326

Miranda, J., Maricato, R., Nova, J.V., Baptista, J.M., Monteiro, J.L., Freitas, N., Gonçalves, O., Vale, V. and Azul, A.M. (2016). Interdisciplinary and Participatory Research at Early Childhood to Biodiversity Education and Sustainable Development. In *Biodiversity and Education for Sustainable Development* (pp. 265-285). Springer, Cham. doi:10.1007/978-3-319-32318-3_17.

Morton, B.G., Gregorio, J., Rosen, D.S., Vallet, R. and Kim, Y. (2017). STEAM Education through Music Technology (Evaluation). Paper presented at 2017 American Society for Engineering Education (ASEE) *Annual Conference & Exposition*, Columbus, Ohio. 10.18260/1-2—28841

Mun, K., Mun, J., Hwang, Y., & Kim, S. (2017). Changes in High School Students' Creative Leader Competency through STEAM R&E. *Journal of the Korean Association for Science Education*, 37(5), 825-833.

National Science Foundation (2013). *Common Guidelines for Education Research and Development.* Institute of Education Sciences.

New Zealand Ministry of Education (2020). WAPA 2020 Cluster – STEAM in the junior school. Accessed 18 Oct 2021. Available:https://nzcurriculum.tki.org.nz/Curriculum-resources/Schoolsnapshots/WAPA-2020-cluster

Ng, W., and Fergusson, J. (2020). Engaging High School Girls in Interdisciplinary STEAM. *Science education international*, 31: 283-294.

Nitsche, Michael and Crystal Gillett (2020). Framing Craft and Performance in Hybrid Puppetry Workshops. *Design and Technology Education*, 25(1): 96-116.

O'Connor, G & Stevens, C. (2015). Combined art and science as a communication pathway in a primary school setting: Paper and ice. *Journal of Science Communication,* 14(4), A04. doi:10.22323/2.14040204.

Ofori-Boadu, A., Deng, D., Stephens, C.M. and Gore, K. (2019). Learning Experience and Self-Efficacy of Minority Middle School Girls during a "Bio-char Modified Cement Paste Research Program at an HBCU, Paper presented at 2019 American Society of Engineering Education *(ASEE) Annual Conference and Exposition*, Tampa, Florida. 10.18260/1-2—33051

Ong, K.J., Chou, Y.C., Yang, D.Y., and Lin, C. (2020). Creative Drama in Science education: The Effects on Situational Interest, Career Interest, and Science-Related Attitudes of Science Majors and Non-Science Majors. *Eurasia Journal of Mathematics, Science and Technology Education,* 16(4): 1831

Overton, D.T. and Chatzichristodoulou, M. (2010). The Teaching of Science through the Performing Arts, Procedia *Social and Behavioral Sciences*, 2, 3871–3875.

Parekh, P. and Gee, E.R. (2018). Zooming into a Tinkering Project: The Progression of Learning through Transitional Objects, *Interdisciplinary Journal of Problem-Based Learning*, 12(2). https://doi.org/10.7771/1541-5015.1751

Peleg, R. and Baram-Tsabari, A. (2017). Learning Robotics in a Science Museum Theatre Pay: Investigation of Learning Outcomes, Contexts and Experiences, *Journal of Science Education Technology, 2*6: 561-581.

Peppler, K.A. (2010). Media Arts: Arts Education for a Digital Age, Teachers College Records, 112(8): 2118-2153. Parekh, P. and Gee, E.R. (2018). Zooming into a Tinkering Project: The Progression of Learning through Transitional Objects, *Interdisciplinary Journal of Problem-Based Learning,* 12(2). https://doi.org/10.7771/1541-5015.1751

Poldberg, M. M, Trainin, G., & Andrzejczak, N. (2013). Rocking your Writing Program: Integration of Visual Art, Language Arts, & Science. *Journal for Learning through the Arts*, 9(1), 3–20. http://dx.doi.org/10.21977/D9912659

Pool, J., Dittrick, C., & Pool, K (2011). Arts Integration in Teacher Preparation, *Journal for Learning through the Arts,* 7(1). https://doi.org/10.21977/D97110004.

Queiruga-Dios, M.-Á., López-Iñesta, E., Diez-Ojeda, M., Sáiz-Manzanares, M.-C., Vázquez-Dorrío, J.-B. (2021). Implementation of a STEAM project in compulsory secondary education that creates connections with the environment. *Journal for the Study of Education and Development,* 44(4): 871-908.

Rudd, J.A., Horry, R. and Skains, R.L. (2020). You and CO2: A Public Engagement Study to engage Secondary School Students with the Issue of Climate Change. *Journal of Science Education and Technology,* 29: 230-241.

Ruiz-Mallén, I., Gallois, D. and Heras, M. (2018). From White Lab Coats to Actual Scientists: Exploring the impact of researcher interaction and performing Arts on students' perceptions and motivation for science. *Science Communication*, 40(6): 749-777.

Sáez-López, J.M & Sevillano-García, M. L. (2017). Sensors, programming and devices in Art Education sessions. One case in the context of primary education. Cul*ture and Education, 29(*2), 350-384. doi:10.1080/11356405.2017.1305075

Salmi, H., Thuneberg, H., Bogner, F.X. and Fenyvesi, K. (2021). Individual Creativity and Career Choices of Pre-teens in the Context of a Math-Art Learning Event', *Open Education Studies,* 3: 147-156.

Schoevers, E., Leseman, P., & Kroesbergen, E. (2019). Enriching Mathematics Education with Visual Arts: Effects on Elementary School Students' Ability in Geometry and Visual Arts. *International Journal of Science and Mathematics Education,* 18(8), 1613-1634. https://doi.org/10.1007/s10763-019-10018-z

Scottish Government (2020). STEM Strategy for Education and Training in Scotland. Accessed 19 OCT 2021. available: file:///C:/Users/User/Downloads/stem-strategy-education-training-scotland-second-annual- scotland-second-annual-report%20(1).pdf report%20(1).pdffile:///C:/Users/User/Downloads/stem-strategy-education-training-

Sharma, R., Gordon, M., Dharamsi, S., & Gibbs, T. (2015). Systematic reviews in medical education: a practical approach: AMEE Guide 94. *Medical Teacher, 37*(2), 108–124.

Shin. C. (2005). *Introduction to education*. Goyang: SeoHyun.

Snyder, L., Klos, P. & Grey-Hawkins, L. (2014). Transforming Teaching through Arts Integration: AI Implementation Results: Middle School Reform through Effective Arts Integration Professional Development. *Journal for Learning through the Arts*, 10(1): 1-26.

So, H. J., Ryoo, D., Park, H., & Choi, H. (2019). What Constitutes Korean Pre-service Teachers' Competency in STEAM Education: Examining the Multi-functional Structure. *Asia-Pacific Education Researcher*, 28(1), 47-61. https://doi.org/10.1007/s40299-018-0410-5

Stagg, B.C. (2020). Meeting Linnaeus: Improving comprehension of biological classification and attitudes to plants using Drama in primary science education. *Research in Science and Technological Education,* 38(3): 253-271.

Stagg, B.C. & Verde, M.F. (2019). Story of a Seed: Educational theatre improves students' comprehension of plans reproduction to plants in primary science education. *Research in Science and Technological Education,* 37(1): 15-35.

Sullivan, A., Bers, M.U. (2018). Dancing robots: integrating art, music, and robotics in Singapore's early childhood center. *International Journal of Technology and Design* Education. 28, 325–346. https://doi.org/10.1007/s10798-017-9397-0

The Swedish National Agency for Education- Skolverket (2018)*. Curriculum for the compulsory school, preschool class and school-age educare. Revised 2018.* Accessed 19 Oct 2021. Available: https://www.skolverket.se/getFile?file=3984

Thuneberg, H. M., Salmi, H. S., Bogner, F. X. (2018). How creativity, autonomy and visual reasoning contribute to cognitive learning in a STEAM hands-on inquiry-based math module. *Thinking Skills and Creativity*, 29: 153-160.

Torralba, J. (2019). A mixed-methods approach to investigating proportional reasoning understanding in maker-based integrative steam projects. *Fablearn 2019 8th Annual Conference on Maker Education,* Teachers College, Columbia University, New York; March 10th, 2019.

Trott, C.D., Even, T.L. and Frame, S.M. (2020). Merging the Arts and sciences for collaborative sustainability action: a methodological framework. *Sustainability Science*, 15: 1067-1085.

Walker, E., Tabone, C. & Weltsek, G. (2011). When Achievement Data Meet Drama and Arts Integration. *Language Arts*, 88(5): 365-372.

Walsh, E., Smullen, E., & Cordero, E. (2018). “My Favorite Part is When We Tell the Truth”: Identity and Agency in Middle School Youth’s Climate Science Digital Storytelling. In Kay, J. and Luckin, R. (Eds.) *Rethinking Learning in the Digital Age: Making the Learning Sciences Count, 13th International Conference of the Learning Sciences* (ICLS) 2018, Volume 3. London, UK: International Society of the Learning Sciences.

Ward, S.J., Price, R.M., Davis, K. and Crowther, G.J. (2018). Song writing to learn: how high school science fair participants use Music to communicate personally relevant scientific content. *International Journal of Science Education*, 8(4): 307-324.

Welsh Government, (2008). *Curriculum for Wales, Key Stages 2-4*. Accessed 19 Oct 2021, available:*https://hwb.gov.wales/curriculum-for-wales-2008/key-stages-2-to-4/#curriculum*

Yliverronen, V., Rönkkö, M.-L., & Kangas, K. (2021). Learning everyday technologies through playful experimentation and cooperative making in pre-primary education. *FormAkademisk - Forskningstidsskrift for Design Og Designdidaktikk*, 14 (2). doi:10.7577 / formakademisk.4198

Young-Mi, K. & Hye-Jeon, H. (2016). The effects of “Physics, Let’s Dance,” as an integrated dance art education program related to science subject, on the personality and creative thinking ability of elementary school students. *Indian Journal of Science and Technology*, 9(29). doi:10.17485/ijst/2016/v9i29/94754

Appendices

Appendix A

LIST OF HAND SEARCHED JOURNALS

- American Educational Research Journal
- British Journal of Educational Technology
- Canadian Journal of Learning and Technology
- Computers & Education
- Educational Technology Research and Development
- Eurasia Journal of Mathematics, Science and Technology Education
- European Journal of Engineering Education
- European Journal of STEM Education
- International Journal of Art and Design Education
- International Journal of Cognitive Research in Science, Engineering and Education
- International Journal of Education in Mathematics, Science, and Technology
- International Journal of Education through Art
- International Journal of Education and the Arts
- International Journal of Engineering Education
- International Journal of Engineering Pedagogy
- International Journal of Interdisciplinary Educational Studies
- International Journal of Mathematical Education in Science and Technology
- International Journal of Mobile and Blended Learning
- International Journal of Music Education
- International Journal of Science and Mathematics Education
- International Journal of Science Education

- International Journal of STEM Education
- International Journal of Technology and Design Education
- Journal of Computers in Mathematics and Science Teaching
- Journal of Engineering Education
- Journal of Pre-College Engineering Education Research
- Journal of Professional Issues in Engineering Education and Practice
- Journal of Research in Science Teaching
- Journal of Research in STEM Education
- Journal of Science Education and Technology
- Journal of STEM Education: Innovations and Research
- Journal of STEM Outreach
- Journal of Technology and Science Education
- Research in Science and Technological Education
- School Science and Mathematics
- Science Education
- Technology, Pedagogy and Education
- The Journal of Educational Research
- World Transactions on Engineering and Technology Education

Appendix B

Population	**Intervention (STEM context)**	**Intervention (STEAM context)**
Early childhood edu*	STEM	STEAM
Early Years Education	ST*M	
Kindergarten		Art*
	Science	Arts
Primary school*	Technology	Visual Arts
Primary edu*	Engineering	Performing Arts
Elementary school*	Math*	Music
Elementary Edu*		Drama
	Maker Space*	
Middle school*		Art* integration
Middle edu*	Inter?disciplinary	Creative ability
	Multi?disciplinary	
Post-primary school*		
Post-primary edu*		
High?school*		
Edu*		

Table 1: An initial list of keywords was formulated under an adapted version of the PIO Framework for vocabulary selection

Boolean	stem OR stm OR science OR technology OR math OR engineering AND early years education OR school or primary STEAM Education NOT undergraduate OR college OR university OR higher education
Phrases	"STEAM Education" AND "early childhood education"
Truncation*	Early childhood educ*
Wildcard	ST?M
Parentheses	"STEM Education OR STEAM Education" AND "early childhood education" AND

Table 2: Sample searches using relevant Search Syntax

Appendix C

SEARCH QUERIES USED WITHIN EACH OF THE FIVE CATEGORIES OR POPULATIONS

Population/category	Search query
Early Years	((((TS=(early childhood edu*)) OR TS=(early year edu*)) OR TS=(pre?school)) OR TS=(kindergarten)) AND TS=(STEAM)
	((((((TS=(early child* edu*)) OR TS=(early years edu*)) OR TS=(pre?school)) OR TS=(kindergarten)) AND TS=(stem)) AND TS=(art)) and Articles or Proceedings Papers or Early Access (Document Types)
	(((((TS=("early child* edu*")) OR TS=("early years edu*")) OR TS=(pre?school)) OR TS=(kindergarten)) AND TS=(technology)) AND TS=(art)
	(((((TS=("early child* edu*")) OR TS=("early years edu*")) OR TS=(pre?school)) OR TS=(kindergarten)) AND TS=(science)) AND TS=(arts)
	(((((TS=("early child* edu*")) OR TS=("early years edu*")) OR TS=(pre?school)) OR TS=(kindergarten)) AND TS=(engineering)) AND TS=(arts)
	(((((TS=("early child* edu*")) OR TS=("early years edu*")) OR TS=(pre?school)) OR TS=(kindergarten)) AND TS=(maths)) AND TS=(arts)

Primary	((((TS=("primary school*")) OR TS=("primary edu*")) OR TS=("elementary school*")) OR TS=("elementary edu*")) AND TS=(STEAM)
	(((((TS=("primary school*")) OR TS=("primary edu*")) OR TS=("elementary school*")) OR TS=("elementary edu*")) AND TS=(STEM)) AND TS=(art)
	(((((TS=("primary school*")) OR TS=("primary edu*")) OR TS=("elementary school")) OR TS=("elementary edu*")) AND TS=(technology)) AND TS=(art)
	(((((TS=("primary school*")) OR TS=("primary edu*")) OR TS=("elementary school")) OR TS=("elementary edu*")) AND TS=(science)) AND TS=(art)
	(((((TS=("primary school*")) OR TS=("primary edu*")) OR TS=("elementary school")) OR TS=("elementary edu*")) AND TS=(math)) AND TS=(art)
	(((((TS=("primary school*")) OR TS=("primary edu*")) OR TS=("elementary school")) OR TS=("elementary edu*")) AND TS=(engineering)) AND TS=(art)
Second Level	(((((TS=("secondary school")) OR TS=("secondary edu*")) OR TS=("middle school")) OR TS=(post?primary)) OR TS=(high?school)) AND TS=(STEAM)

	((((((TS=("secondary school")) OR TS=("secondary edu*")) OR TS=("middle school")) OR TS=(post?primary)) OR TS=(high?school)) AND TS=(STEM)) AND TS=(art)
	((((((TS=("secondary school")) OR TS=("secondary edu*")) OR TS=("middle school")) OR TS=(post?primary)) OR TS=(high?school)) AND TS=(technology)) AND TS=(art)
	((((((TS=("secondary school")) OR TS=("secondary edu*")) OR TS=("middle school")) OR TS=(post?primary)) OR TS=(high?school)) AND TS=(science)) AND TS=(art)
	((((((TS=("secondary school")) OR TS=("secondary edu*")) OR TS=("middle school")) OR TS=(post?primary)) OR TS=(high?school)) AND TS=(math*)) AND TS=(art)
	((((((TS=("secondary school")) OR TS=("secondary edu*")) OR TS=("middle school")) OR TS=(post?primary)) OR TS=(high?school)) AND TS=(engineering)) AND TS=(art)
Informal Education	((((TS=("after school prog*")) OR TS=(library)) OR TS=("summer camp*")) OR TS=("summer prog*")) AND TS=(STEAM)
	((((TS=("after school prog*")) OR TS=(library)) OR TS=("summer camp*")) OR TS=("summer prog*")) AND TS=("STEAM edu*")
	((((TS=("after school prog*")) OR TS=(library)) OR TS=("summer camp*")) OR TS=("summer prog*")) AND TS=("STEAM learning")
	TS=("STEAM prog*")

STEAM	((((TS=(maker?space)) OR TS=("maker edu*")) NOT TS=(university)) NOT TS=("higher edu")) NOT TS=("third level")
	(((TS=("STEAM edu*")) NOT TS=(university)) NOT TS=("higher edu*")) NOT TS=("third level")
	(((TS=("STEAM teaching*")) NOT TS=(university)) NOT TS=("higher edu*")) NOT TS=("third level")
	(((TS=("STEAM learning*")) NOT TS=(university)) NOT TS=("higher edu*")) NOT TS=("third level")
	((((TS=("STEM and art")) OR TS=("STEM and arts")) NOT TS=(university)) NOT TS=("higher edu*")) NOT TS=("third level")
	((((TS=("arts integration")) OR TS=("arts integrated instruction")) NOT TS=(university)) NOT TS=("higher edu*")) NOT TS=("third level")

Appendix D

Article id#	Researcher A	Researcher B	Researcher C	Researcher D
1-24	1st reader	1st reader	1st reader	1st reader
24-124	1st reader	2nd reader		
125-225	2nd reader	1st reader		
226-326			1st reader	2nd reader
327-427			2nd reader	1st reader
428-905	1st reader			2nd reader
906-1382		1st reader	2nd reader	
1383-1859		2nd reader	1st reader	
1860- 2064	2nd reader			1st reader