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Special Issue: Promoting STEAM in Education

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Editorial: Special Issue "Promoting STEAM in Education"

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Lately STEAM (science, technology, engineering, art/aesthetics/architecture/all, mathematics) education has become a common notion. Yet, the theoretical and practical perspectives on STEAM, from its nature to classroom applications and its implementation in teacher education have unexamined potential. This special issue grew out of the International LUMAT Research Symposium "Promoting STEAM in Education" that took place at the University of Helsinki, Finland in June of 2020. With the challenges of organizing an online symposium in the midst of the COVID-19 pandemic, its online nature had significant advantages. The symposium drew international scholars inviting a multitude of prospective on STEAM education, while uncovering the challenges faced by educators. The issue aims at examining these challenges through a collection of papers. In this editorial, we introduce some key notions, discourses, and challenges of STEAM education, as a relatively novel concept and briefly discuss the history of STEAM and its evolution over the last decades. We also problematize STEAM and its roots through asking a question: What is "A" in STEAM representing? Then we introduce the three articles in this special issue: "Full STEAM ahead, but who has the map? – A PRISMA systematic review on the incorporation of interdisciplinary learning into schools"; Promoting STEAM learning in the early years: 'Pequeños Científicos' Program"; and "Promoting student interest in science: The impact of a science theatre project". These articles challenge us to rethink STEAM education, reveal the potential of STEAM, and offer ideas for future research.

Keywords: art education, interdisciplinarity, STEM education, STEAM education, teacher education

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1 Why STEAM? Why now?

1.1 Conceptualization of STEAM and exploring its drivers and potential

In recent years, the acronym STEAM has become ubiquitous in the educational literature, policy, and research. Yet despite its increasing presence, it is not entirely clear whether STEAM is to be conceptualized as a phenomenon, a movement, a pedagogical approach, a policy or a new perspective (Martinez, 2017; Perignat & Katz-Buonincontro, 2019). Furthermore, albeit four of the letters in the acronym, S-T-E-M have been historically conceptualized as "Science", "Technology", "Engineering" and "Mathematics", the fifth letter 'A' appears to be ambiguous, most often denoting both narrow and wide conceptualizations of "Art(s)" (Ge, Ifenhaler, & Spector, 2015), but also allowing for "Aesthetic(s)" (Segarra, Natalizio, Falkenberg, Pulford, & Holmes, 2018) and even "All" (White, 2014). STEAM education is still in its infancy whilst the STEM concept has had the time to mature since its introduction by the US National Science Foundation (NSF) in the early 2000s, growing out of its earlier counterpart SMET from the 1990s (Sanders, 2009) and sharing goals with the well-established STS movement (McComas, 2014). This is, however, not to say that STEM has been clearly conceptualized (see e.g., the special issue of Science & Education, no. 4/2020 on the nature of STEM) or that there is a universal agreement on what it represents (Erduran, 2020).

While the connections of science, technology, engineering, arts, and mathematics have been an integral part of the western culture for centuries (Isaacson, 2017), the more recent constructions relevant to education, such as STEM and STEAM are man-made and were driven by many different forces, some of which lay outside of the education system. Thus, we should not necessarily expect to readily or easily arrive at universally applicable rigid and immutable definitions or conceptualizations. Rather, these conceptualizations are products of our constant explorations, discussions and negotiations with the goal of creating meaningful learning environments for the learners in order to give every student an opportunity to engage in the study of these fields from kindergarten to tertiary education, also including informal learning contexts as well as life-long learning. While nowadays, STEM education might not be driven by a cold war or a space race as it was half a century ago, (Dickson, 2001; Moritz, 1999; Pion & Lipsey, 1981), the challenges of the 21st century have provided plenty of new reasons for engaging all students in STEM. STEM-related education might help address pressing societal issues. Some of them are related to environmental degradation, climate change, and unsustainable development (UNESCO, 2017). While others reflect the growing economic gaps, lack of social mobility, and the ongoing failure to engage underrepresented groups, such as immigrants, in STEM fields (Chachashvili-Bolotin, Lissitsa, & Milner-Bolotin, 2019; Chachashvili-Bolotin, Milner-Bolotin, & Lissitsa, 2016) .

At the same time, scholars have raised a critique of STEM approaches, such as taking for granted that an integrated instructional blending of STEM is unequivocally desired (McComas & Burgin, 2020). This should also be relevant when considering the future of STEAM education as described below.

1.2 From STEM to STEAM

Along with the discussions and research on STEM subjects, policy makers and researchers have expressed concerns about what is seen as a narrow focus of STEM education, when economic growth is seen as the major success factor in societies and STEM is seen as the means to achieve this (McComas & Burgin, 2020). In addition, the lack of family STEM engagement has been identified as one of the major factors negatively affecting student disengagement from STEM, especially the students from low socio-economic backgrounds and immigrants (Marotto & Milner-Bolotin, 2018; Milner-Bolotin & Marotto, 2018). As a result, arguments have been put forward to broaden perspectives on STEM education in order to include the previously mentioned 'A'. Thereby, expanding STEM into STEAM acknowledges other parts of human existence as equally important and valuable as the domains covered by STEM (Colucci-Gray, Burnard, Cooke, et al., 2017). Another argument for an expansion of STEM into STEAM has been to address the challenges of the 21st century, and to promote 21st century skills, such as educating citizens capable of seeing and exploring interconnections within STEM subjects and between STEM and other areas, such as everyday life (Ge et al., 2015; Hopia & Fooladi, 2019; Milner-Bolotin & Milner, 2017). In order to achieve such ambitious goals, we have to educate teachers who can support students in becoming STEAM-literate citizens and see STEM and STEAM outside the classroom walls (Harris & de Bruin, 2018; Perignat & Katz-Buonincontro, 2019). For example, it is said that in addition to educating citizens who are literate in basic science and mathematics, it is important to educate students who are curious and knowledgeable about how things work (Engineering) (Bloomfield, 2001; Milner-Bolotin & Svinicki, 2000), how science is embedded in everyday life experiences, such as cooking (Fooladi, 2013; Fooladi, 2019; Hopia & Fooladi, 2019), how technology is affecting our lives, and how all this links to other areas of society and life come together to solve omnipresent societal problems (Arts, Aesthetic(s), All). Likewise, in dealing with complex issues locally, regionally, and globally it is expected from present and future leaders to be able to see how these issues are interconnected and weaved into each other, as the basis for sound decision-making processes (Muller, 2008). This is clearly applicable to the issue of sustainable development and sustainability education. In short, to be able to address the 21st century challenges, inter-/multi-/transdisciplinary approaches are crucial, giving legitimacy to exploring interconnections between STEM and other subject domains in education.

According to Colucci-Gray and collaborators (2017, p. 31), "[t]he STEAM literature echoes a view of the arts as valuable both intrinsically and instrumentally; the arts are deemed to be social, inclusive, humanizing, and thereby significant for human development in the society (Belfiore and Bennett 2007; Canatella 2015)."Hence, the role of the 'A' can be considered *supporting* the goals of STEM, it might be considered *expanding* STEM to include broader perspectives, or it might be considered *bringing to the table something unique and different*, but significant, that is entirely different from STEM but still required for achieving some form of completion. In any case, the meeting, or integration, of STEM with 'A' represents an encounter that brings with its possibilities, challenges and power relations. As described above, 'A' can play an instrumental role in helping STEM achieve its goals, whichever those may be. At this end of the spectrum, 'A' basically plays a service role in support of STEM. At the other end of the spectrum, STEM may be brought in to support learning, or understanding, of 'A'. Between these extremes, there are a multitude of modes of collaboration and integration, for which there appears to be no consensus as to which is to be preferred or recommended along a normative scale. As STEAM is still in its infancy, a pluralist stance may be a productive path while we can follow the development of a breadth of approaches to STEAM. The three articles in this special issue indeed display a broad variation in scope, focus and style. They also represent different approaches to STEAM education implemented across the globe as opposed to focusing on STEAM education in a particular country.

1.3 The goals of the current issue

This present special issue of the LUMAT Journal builds on the 2020 International LUMAT Symposium with the title "Promoting STEAM in Education" (Aksela, Vesterinen, Herranen, & Pernaa, 2020). An open interpretation of 'A' in the STEAM acronym has been chosen deliberately, where 'A' is conceptualized to be situated closer to "All" than a traditional narrower conceptualization of A as representing the "Art(s)". Whichever definition or conceptualization is chosen for STEAM, it will inevitably shape how STEAM education is practiced and researched (Colucci-Gray, Burnard, Cooke, et al., 2017; Colucci-Gray, Burnard, Gray, & Cooke, 2017). Laying aside discussions on STEM, which is outside the scope of this special issue, the challenge remains, to discuss the relationship between STEM and the 'A'. Reviewing existing STEAM research, Colucci-Gray et al. (2017) concluded that if 'A' in STEAM includes all that is missing from STEM, a researcher's definition of STEAM would reflect what is missing or problematic in STEM, such as the ethical, aesthetic and affective dimensions (Colucci-Gray, Burnard, Gray, et al., 2017).

The aim of this special issue is to unravel the potential of STEAM in a variety of educational contexts. According to the studies in this issue, STEAM has possibilities, not yet examined or even considered. The three articles also discuss some challenges in the practical approaches to STEAM education, connected to its multidisciplinary nature, the local contexts, and the practicalities in its implementation.

2 Papers included in the current issue

The first article by Seamus Delaney and Daniel White, "*Full STEAM ahead, but who has the map? – A PRISMA systematic review on the incorporation of interdisciplinary learning into schools*", reviews existing literature on interdisciplinary STEAM learning and teaching in high schools. The reviewed articles showed that improved learning outcomes, such as better results in academic tests, could be achieved in project- and problem-learning environments. In addition, the authors find that STEAM-based approaches in interdisciplinary teaching could potentially increase student collaboration and interaction with professionals. However, in the screening phase for the review only eleven articles out of ninety-nine potential publications met the criteria for inclusion in the synthesis, namely that the research should measure in some way learning outcomes from STEAM-oriented teaching. Therefore, the authors argue that more empirical research is required on the relationship between STEAM and learning outcomes before such STEAM approaches are implemented in educational systems on a large-scale.

The second article *"Promoting STEAM learning in the early years: 'Pequeños Científicos' Program"* by Valeria Cabello, Maria Loreto Martinez, Solange Armijo Solis, and Lesly Maldonado describes and examines a non-formal education program among 3–10-year old children. Aiming at inspiring young girls' interest in STEM/STEAM subjects, the program was taught by an all-female staff of scientists and artists on topics including historical accounts of women's roles in STEM, thus seeking to curb gender-stereotypes and male domination in STEM. The article discusses the strengths, weaknesses, and opportunities of the program based on the perceptions of the students, teachers, and educators. A number of strengths of the program were identified: the students were engaged in learning processes; holistic perspectives and integration between STEM and 'A' were achieved and clear signs were found of increased motivation and interest among the participants. One of the major challenges identified in this program was the handling of young learners' emotions, frustration and behavior by an all-scientists/artist staff with limited or no pedagogical background in handling such issues.

The third article *"Promoting student interest in science: The impact of a science theatre project"* by Lydia Schulze Heuling reports on a science theatre project in a heterogeneous teaching context in a disadvantaged area, and its effects on students' interest in STEM and their artistic expression. The quantitative analysis presented in the study indicated an increased student interest in the topic of galvanization, and physics and chemistry in general. In addition, the approach resulted in increased student appreciation of artistic practices and positive classroom spirit, knowledge of cultural practices, and student self-confidence. Based on this work, the author discusses art-informed STEM education as a socially inclusive practice.

3 Conclusions

The three articles in this issue point to the holistic nature of STEAM in education, as expressed by the variety of approaches to and a multitude of motivations for STEAM in education at all levels of the education system. This should come as no surprise, as new subject and knowledge domains are included, more possibilities and challenges are introduced. In line with Colucci-Gray and collaborators, the research and education community could benefit from future studies on STEAM education extending beyond small-scale projects, while also considering the long-term implications of STEAM education (Colucci-Gray, Burnard, Cooke, et al., 2017; Colucci-Gray, Burnard, Gray, et al., 2017).

The research and education communities continue to explore and debate various aspects of STEM and their implications (Erduran, 2020; McComas & Burgin, 2020). When STEM is expanded into STEAM, a further complexity is added, as yet another element, itself highly complex and with its own challenges, is introduced into the mix.

Within STEAM, science, technology, engineering, and mathematics educators, teacher educators, and researchers must engage in a dialogue and meaningful collaborations with colleagues from other areas, such as language and literature, music, visual arts, drama, home economics, social sciences, and other subject domains (Herranen, Kousa, Fooladi, & Aksela, 2019). Whether 'A' is conceptualized as "art(s)", "aesthetics", "architecture", or "all", it is to be expected that cultural meetings between epistemologies and ontologies of different subject domains will provide exciting possibilities as well as substantial challenges. This calls for not only expertise in one's own field of work, but also insights into other subject domains, respect for your "out-of-your-field" colleagues' way of working and thinking, and willingness to put oneself in their shoes. As such, STEAM education could also provide a path to building mutual understanding across professional cultures and knowledge domains, as well as motivate learners, and contribute to solving societal and global issues.

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Full STEAM ahead, but who has the map for integration? – A PRISMA systematic review on the incorporation of interdisciplinary learning into schools

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Science, Technology, Engineering and Mathematics or "STEM" focused pedagogy has been influenced changes in education for decades. Responding to the need for interdisciplinary skilled workforces, the STEM approach has been revised firstly to reflect the incorporation of Arts, (STEAM) and, more recently, to place stronger emphasis on cross-disciplinary connections. However, there is little empirical evidence to drive the development of a practical model for classroom implementation. This systematic review aims to consolidate existing empirical evidence on the incorporation of interdisciplinary learning via a STEM/STEAM approach in high-school environments using a PRISMA review scaffolding. The review identified ninety-nine articles that addressed interdisciplinary learning. However, the majority of them were excluded due to the lack of empirical evidence for such improvements, resulting in only eleven studies being included in the final synthesis. This suggests that more research is required prior to wide-scale implementation within high school education systems. Of those that met the selection criteria, the overarching theme was that improved outcomes were best achieved via either a real-world project-based or problem-based learning pedagogy with the use of community and industry support. However, due to the low number of studies found to fit the criteria, it is recommended that further research is conducted to provide greater empirical evidence to support this finding.

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1 Introduction

The phrase "STEM education" is used to describe a focus on the teaching of, and the learning within Science, Technology, Engineering, and Mathematics (STEM) fields (Gonzalez & Kuenzi, 2012). A focus on STEM rose to prominence in the US educational arena in response to the ongoing low performance of American students in mathematics and science on international assessments, such as TIMSS and PISA (Breiner, Harkness, Johnson, & Koheler, 2012; Gonzalez & Kuenzi, 2012; Klein, 2008; Marinova & McGrath, 2004; McClam & Flores-Scott, 2012; Roehrig, Moore, Wang, & Park, 2012; Savage, 2012; Wang, Moore, Roehrig, & Park, 2011). Many other countries faced similar challenges and placed an importance on STEM linked subjects within their educational framework (Corlu, Capraro, & Capraro, 2014; Scholz, Lang, Wiek, Walter, & Stauffacher, 2006; Yakman & Lee, 2012). In Australia, STEM education emphasis was implemented as a means of developing a "21st century orientated" workforce (Price Waterhouse Coopers Australia, 2018; Taylor, 2016) as it became apparent that employment, irrespective of the field or level, required knowledge and capabilities within the disciplines covered by STEM-related disciplines (Al Salami, Makela, and Miranda, 2017; Breiner et al., 2012; Corlu et al., 2014) and there was a need for STEM literacy and capabilities within the population (Scholz et al., 2006). This emphasis has continued within both educational research and its practical application in the classroom. For example, Science & Education recently published an entire issue addressing STEM education research and its application (Erduran, 2020).

Originally, STEM education could be considered as a focus on teaching and learning within the separate and distinct disciplines that make up the acronym (Science, Technology, Engineering, Mathematics) with little or no overlap between the educational experience within. Recently in response to pressure on the curriculum developers to ensure that education should reflect the real-world, STEM education has been transformed into a multidisciplinary educational approach with a stronger emphasis on integrating the learning across these disciplines. Integrated STEM education could be considered as an approach that incorporated content of two or more STEM domains for the purpose of enhancing the learning outcomes of the student. Proponents of this curricular change argue that such a teaching platform reflects more real-world parallels (Breiner et al., 2012; Taylor, 2016; Wang et al., 2011). Creating disciplinary boundaries between the components creates an inefficient instruction model for students and limits their capacity to transfer their classroom learning into the real world. Furthermore, some Academics believe that the problem-solving approaches developed within the integrated STEM paradigm are needed to create innovative thinkers with interdisciplinary capabilities (Brown, 2012; Corlu et al., 2014; Madden et al., 2013). Such thinkers are required to address the complex issues facing the world today, such as social and economic inequality and climate change (Corlu et al., 2014; McClam & Flores-Scott, 2012; Savage, 2012; Spelt, Biemans, Tobi, Luning, & Mulder, 2009; Webber & Miller, 2016).

Terms such as *interdisciplinary, transdisciplinary* and *integrated* are often used to describe integrated STEM educational approach (Keane & Keane, 2016; Klein, 1990; McClam & Flores-Scott, 2012; Taylor, 2016). It is worth noting from the outset of this review, that this field of educational innovation has been fraught with a plethora of different terminology and conceptualisations, many of which either strongly overlap or describe similar phenomena (Brown, 2012; Wang et al., 2011). As such, what one researcher may refer to as Transdisciplinary, another will label it Interdisciplinary. Table 1 highlights some of the key components of the different terminology. While there is some variation in the literature in the use of these terms, these definitions were selected as being as being representative of the generally accepted conceptualisation of the terms and highlight the clear demarcation between the concepts that they encompass.

Table 1. Different interpretations of the thinking arising from integrated STEM/STEAM pedagogy

Forms of Thinking	***Conceptualisation***	***References***
Multidisciplinary thinking	Combinations of thinking arising from learning in different disciplines but with distinct and clear lines of demarcation between them. In this regard, Multidisciplinary can be thought of as an additive.	Marinova and McGrath, 2004; McClam and Flores-Scott, 2012; Park and Son, 2010; Spelt et al., 2009.
Interdisciplinary thinking	The ability to synergise knowledge from multiple disciplines in a way that leads to an understanding or outcome that would not have been possible from drawing information from a single discipline. Interdisciplinary programs focus on the collaboration and interaction between the disciplinaries. In this regard, interdisciplinarity can be thought of as integrative.	Klein, 1990; Marinova and McGrath, 2004; Spelt et al., 2009; McClam and Flores-Scott, 2012; Park and Son, 2010; Wang et al., 2011.
Transdisciplinary thinking	Transdisciplinary focuses on the outcome where the boundaries between the disciplines are not relevant and creation of new knowledge is the focus. The goal of transdisciplinary learning is to foster holistic global understanding and appreciation for the unity of knowledge. In this regard, Transdisciplinary can be thought of as inclusive.	Marinova and McGrath, 2004; McClam and Flores-Scott, 2012; Park and Son, 2010; Wang et al., 2011.

In even more recent times, this 'real-world' push has resulted in a tendency for Arts to be incorporated into the traditional STEM program, moving from STEM to STEAM to better achieve this goal of developing complex problem solvers. Table 2 gives a brief overview of some of the key conceptualisations of this approach. The justification for this is that the development of innovative and creative problem solvers requires the "creativity" component that a STEAM-based curriculum would provide compared to a strictly STEM curriculum (Madden et al., 2013) and that the integration of Arts subjects (i.e. liberal arts, social studies, physical and fine arts and music) within STEM aids in the development of higher-order abilities to deal positively and productively with 21st century global challenges (Taylor, 2016; Madden et al., 2013). While the capacity to develop creativity within STEM through the addition of Arts is a contested issue (Martins Gomes & McCauley, 2021, Le Grande, 2018, Root-Bernstein, 2001), proponents of the inclusion argue that the traditional STEM components focus on convergent skills, so the inclusion of Arts will allow for divergent skills acquisition as well (Land, 2013). In addition, findings by Rinne, Gregory, Yarmolinskaya and Hardiman (2011) suggested that utilising components of the Arts pedagogy may result in improved long-term content retention in students. Similar to this, Inoa, Weltske and Tabone (2014) found that students within Art-integrated classes showed improved mathematics scores.

With such strong educational policy change, support, investment, literature and research into integrated STEM/STEAM education, it is surprising then that there is not stronger evidence of improvements in the areas that lead to an emphasis on STEM education in the first place. For example, recent results would suggest that the STEM deficiency is still occurring (Klein, 2008; Land, 2013; Marinova & McGrath, 2004; Stubbs & Myers, 2016; Wang et al., 2011) and there has not been the expected improvements in STEM education outcomes (Gonzalez & Kuenzi, 2012; Sanders, 2009). Gonzalez & Kuenzi (2012) for example identify ongoing concerns with academic achievement gaps, teacher quality and the ability to meet the labor market demands for STEM labor. The final concern is of particular note as this was, in part, the aspect of the education programs that fuelled the reorientation towards STEM in the first place.

Table 2. A brief description of the key conceptualisations of STEM education

Acronym/ Termin-ology	***Description and explanation***	***Example(s) of usage***
MST/SMT	A very early incarnation with a focus on Mathematics, Science and Technology.	Kelley, 2010; Thomas and Williams, 2009.
S-T-E-M.	A stronger emphasis on the development of skills in the fields of Science, Technology, Engineering and Mathematics without a focus or emphasis on the interaction between the different fields.	Breiner et al., 2012; Moher, Liberati, Tetzlaff and Altman, 2009; Sanders, 2015; Taylor, 2016; Wang et al., 2011.
Integrated STEM (or iSTEM)	STEM education with a focus on the interaction between the disciplines or a subgroup of those disciplines, alternatively between "STEM" subjects and other disciplines such as those within the Humanities realm of education (i.e. History).	Breiner et al., 2012; Brown, 2012; Corlu et al., 2014; Kelley, 2010; Moher et al., 2009; Taylor, 2016; Wang et al., 2011.
eSTEM	STEM education with a strong digital and technology focus.	Jaeger, 2015.
SteM, sTEm etc	A range of approaches where there is either an unequal focus on the different components, for example "SteM", which denotes a strong emphasis on Science and Mathematics with some reference to Technology and Engineering.	Dugger, 2010.
E S T M.	Integration of components from other disciplines into pre-existing courses, such as including Science/Technology/Mathematics components within an Engineering course.	Dugger, 2010.
STEAM	A more recent incarnation of the pedagogy that promotes the incorporation of Arts within STEM programs. Arts has been argued to provide a platform for greater creativity and divergent thinking.	Al Salami et al., 2017; Land, 2013; Madden et al., 2013; Yakman and Lee, 2012.
STEAM by design	STEAM education that occurs within a "Place base project" paradigm.	Keane and Keane, 2016.
STREAM	Critical reading and/or writing, combined with STEAM.	Root-Bernstein and Root-Bernstein, 2011.

One possibility for this is the lack of empirical evidence-supported guidelines for educators on how to mesh STEAM, particularly in its more recent inter/transdisciplinary incarnation, with existing pedagogies. It could be argued, therefore, that this lack of academic rigour is a contributing factor in why efforts towards true integrated teaching have not always been successful. Supporting this, Hasni, Lenoir and Alessandra (2015) claimed that the field of integrated STEM often makes broad claims but has little evidence to back up this and also argued for more research to be conducted. Drawing from classroom teachers' experiences, Wang et. al. (2011) highlighted that creating an integrated educational approach is a monumental challenge. In practical terms, teachers who are used to teaching in a traditional silo approach may not be prepared for the holistic integrated approach of integrated STEM (El-Deghaidy, Mansour, Alzaghibi, & Alhammad, 2017; Hasni et al., 2015; Stubbs & Myers, 2016; Wells, 2011).

Teachers are not the only individuals within the integrated STEM paradigm to experience difficulties with integrated thinking. Students as well have been shown to have problems learning across discipline and synthesising information from multiple fields (Spelt et al., 2009; Webber & Miller, 2016). Furthermore, while many educational institutes may claim their STEM/STEAM approach is integrated, there is little evidence of such integration occurring (Papacosta, 2007). For example, Breiner et al. (2012) and Hasni et al. (2015) both point out that, while several STEM programs did bring apparent positive benefits to the classrooms, they involve little integration and real-world demonstration of cross-disciplinary work.

In Brown (2012), a study with the explicit focus of exploring the research base of STEM education, of the total 60 articles examined, almost half of the papers were categorised as non-research derived. In addition, none of the articles reviewed provided a suggested means of implementation of STEM education. As concluded by Brown (2012, p. 10) there is a drastic lack of "large studies analysing student performance and engagement in K-12 classrooms". Roehrig et al. (2012) and Savage (2012) both emphasised that the lack of guidelines and models on how to implement such a program is one of the greatest challenges facing K-12 STEM education.

That is not to say there have not been attempts at developing a model for implementation. For example, STEM/STEAM has been discussed in terms of child-centred learning, democratically based classrooms and open-ended fluid curriculum (Rufo, 2013) to name a few. However, there is little data to support these claims and most of the literature rests on theoretical parallels and "assumed" common grounds.

Hasni et al. (2015) and Papacosta (2007) proposed a definition of integrated STEM, which excluded all pedagogical approaches that did not utilise technological/engineering design-based pedagogy without empirical evidence to support such removal. Campbell (2011) provides an in-depth list of basic concepts that need to be addressed in terms of implementation but little practical instruction on how this is to occur or evidence for why these concepts are key to the success of STEAM implementation. In Klein (1990), an article describing the attributes of a STEM school, there is a strong emphasis on the use of design processes, problem-solving and cognitive modelling, however like above there is little evidence to support this as a valid approach to incorporating STEM. Sanders (2009) argues for the use of purposeful design and inquiry and while it fits well within their description of integrated STEM education, they provide little evidence beyond anecdotal stories. Similarly, Hasni et al. (2015), Kasza and Slater (2017) and Henriksen (2014) rely significantly on individual stories and not extensive evidence-based conclusions. Both Sanders (2009) and Yakman and Lee (2012) proposed that STEM/STEAM sits well within the concept of Constructivism and Cognitive Science, however Yakman and Lee (2012) also links it with several other different educational theories. Neither show evidence for why one theory is more relevant than another outside of their own interpretation of what STEM/STEAM means. Webber and Miller (2016) claimed that their framework for the learning theories and pedagogies would lead to reaching the desired learning outcomes. While they too provided a model to describe potential conceptual frameworks, drawing from situated cognition theory, little empirical data was included. While such an analysis of the state of affairs in educational research may seem overly critical, the purpose is not to dismiss the pioneering efforts of these researchers but simply to clarify that although potential paths have been identified, it is now time for the development of strong evidence-based practices.

It is the aim of this systematic review to consolidate what evidence there is regarding the implementation of STEM in its most recent incarnation-interdisciplinary STEAM and its derivatives, to inform future research. The purpose of this study, therefore, is to explore the successful implementation of this educational platform within the high-school arena via evidence-based reports of improved learning in the students. The closest studies to attempt a similar objective have been Brown (2012) and Spelt et al. (2009). Table 3 summarises the ways in which this review will build upon the findings of Brown (2012). In addition, this review will also complement the Spelt et al. (2009) review within this field, that focused on what sub skills need to be developed and what are the typical conditions, by providing empirical support for the models that allow such learning to take place. This study will also provide a similar analysis of the state of educational affairs in terms of research within the secondary or high-school system (as Spelt et al. (2009) focused on higher or tertiary education).

Table 3. Review extensions from Brown (2012)

Included approach	***Achieved by***
Refining the focus on empirical evidence-based reports, an area identified as lacking in the previous analysis.	Inclusion of an exclusion criteria directly related to this aspect of research (EC2).
Expanding the search to include a broader range of journals.	Use of online databases, compared to the peer identified journal selection of Brown (2012) which resulted in 8 journals being selected. This also seemed appropriate considering the greater focus on transdisciplinary learning and the STEM/STEAM paradigm.
A rigorous framework for literature identification.	The PRISMA scaffolding was selected to bring it in line with other systematic reviews (Moher et al., 2009).
Compensation for the automated component of the review (database analysis) that may have caused key articles that use varied terminology to describe similar educational concepts being missed.	Use of more inclusive search terms.

It should be noted that Spelt et al. (2009) distinguished between interdisciplinary (being integrative) and multidisciplinary (being additive). While the differentiation between the terms may be valid, a review of the literature into the evolution of STEM to STEAM and towards interdisciplinary learning would suggest that such a distinction has not been stringently implemented, nor wholeheartedly accepted by educational research. A similar finding was reported by Venville, Sheffield, Rennie and Wallace (2008). Therefore, a number of terms that have been used for similar learning experiences.

Following Spelt et al. (2009) as a template and traditional systematic review protocols, this review will be conducted via a PRISMA directed systematic search within the relevant literature databases, followed by a critical analysis and synthesis of the relevant material identified (Spelt et al., 2009). Although the PRISMA scaffolding was originally developed for health science meta-analysis and systematic reviews, it is also applicable for systematic review-based research in other fields (Moher et al., 2009).

1.1 Research Questions

This systematic review aims to answer the following research questions:

1. What empirical evidence exists that an interdisciplinary learning platform allows for greater learning outcomes for high-school students?
2. What pedagogies are supported by empirical evidence for the successful implementation (as identified by the achievement of greater learning outcomes discussed in Research question 1) of an interdisciplinary learning platform?

Research question 1 was formulated to address the issue that a large component of the support for interdisciplinary learning has been derived from assumed benefits of such a pedagogical approach. As discussed in the review above, these improved learning can be quite broad-ranging and the Authors did not want to limit the review by imposing constraints on what these learning outcomes were appropriate. Therefore, the validity of benefit was not considered only that such achievement of such benefit was supported by empirical evidence. Research question 2 was formulated to address the issue of a lack of a methodology by which interdisciplinary learning can be achieved in the classroom. These questions along with the appreciation for the varied lexicon identified dictated the eligibility criteria of articles included in this review and informed the critical appraisal of their value regarding this review.

2 Methodology

The format for conducting this systematic review follows the steps outlined by Benitti (2012) and the requirements of a PRISMA systematic review (Moher et al., 2009). The key components of the systematic review and how they are reflected in this specific study are:

- Identification of need;
- Development of review protocol;
- Review of the preliminary search;

- Identification and selection of relevant research; and
- Data synthesis and Discussion.

2.1 Identification of need

A review of the literature, which was described above, on the evolution of STEM/STEAM into an interdisciplinary learning platform, identified an apparent scarcity of articles providing an evidence-based methodology for the implementation of such a pedagogy. While there have been several proposed theoretical substrates for interdisciplinary learning, they have provided little practical instruction and evidence to support these instructions for the successful implementation, and thus educators are often without a means of identifying the most relevant methodology for use in their classroom (Kelley & Knowles, 2016; Taylor, 2016; Roehrig et al., 2012; Spelt et al., 2009). In response to this, Yee-King, Grierson and D'Inverno (2017) and Kelley and Knowles (2016) both argue for more evidence on how best to integrate the learning, the learning scaffolding needed, as well as the instruction design appropriate for integrated learning.

2.2 Development of a review protocol

Following the protocol of Spelt et al. (2009), the international online bibliographic databases that were utilised are listed below. The list includes those identified by Spelt et al. (2009), as well as Scopus. In addition, since ERIC was accessed via the meta-database search engine (PROQUEST), a range of other databases were searched concurrently. These databases were accessed via an online university platform. The included databases were:

1. Educational Resources Information Centre (ERIC);
2. the Science Citation Index Expanded (SCI-EXPANDED);
3. the Social Sciences Citation Index (SSCI);
4. the Arts and Humanities Citation Index (AandHCI);
5. the Conference Proceedings Citation Index- Science (CPCI-S);
6. Conference Proceedings Citation Index- Social Science and Humanities (CPCI-SSH);
7. Book Citation Index– Science (BKCI-S);
8. Book Citation Index– Social Sciences and Humanities (BKCI-SSH);
9. Emerging Sources Citation Index (ESCI);

10. Current Chemical Reactions (CCR-EXPANDED);
11. Scopus

The databases were searched concurrently via the PROQUEST meta-database search engine facility. Searches were restricted to peer-reviewed articles, written in English, and published between 1990 and 15/08/2018, the end date of the data collection period for this systematic review.

In contrast to the protocol of the Spelt et al. (2009) study, the chosen search strategy in this study allowed for the search words to appear anywhere within the text. While this may have led to a larger net being cast in terms of the preliminary database results, the expected small number of returns justified the broader range being used to ensure all potentially relevant material was identified.

With the Search word (SW) the use of the OR command was to account for the varied labels that the relevant concept may fall under. The use of the "?" wild card and * truncation were to account for the varied spelling and uses of the different terms, for example, interdisciplinary and inter-disciplinary and integrating and integrative. If the use of either has somehow resulted in the inclusion of a Search word that did not fit with the underlying definition being explored, it was removed. However, this issue did not arise in the search conducted. Further clarity on the use of wild cards and truncation can be found on the proquest website.

- **SW1**. Inter?disciplinary OR Multi?disciplinary OR Trans?disciplinary OR Cross?disciplinary

When determining the search words for this systematic review, the Spelt et al. (2009) definition of an interdisciplinary learning experience was drawn upon to inform the selection. Spelt et al. (2009) pointed out that within interdisciplinary learning there is greater emphasis on students having the capacity not to just understand a single field of learning but to draw from multiple perspectives and integrate them into their studies. From this conceptualisation, they defined the interdisciplinary thinking learning experience as "the capacity to integrate knowledge of two or more disciplines to produce a cognitive advancement in ways that would have been impossible or unlikely through single disciplinary means" (page 365). However, a review of the literature would suggest that while this definition may be valid, the terminology has not been broadly accepted. Whether correctly or incorrectly, numerous authors appear to interpret similar learning experiences as described above as interdisciplinary, multidisciplinary, transdisciplinary and cross-disciplinary. Therefore, to adhere to this definition, and ensure the broadest possible coverage within this review, additional terminology had to be included.

- **SW2**. Integrat*

It was noted that a key component of relevant definitions used by Spelt et al. (2009) and others for this form of learning is the integration of understanding across disciplines (i.e. "the capacity to integrate knowledge of two or more disciplines" (Spelt et al. 2009, p. 365). Therefore, a reference to integration of knowledge was included in this search.

- **SW3**. Secondary OR High?School OR 7-12 OR Middle?School;
- **SW4**. Educat*

Within recent literature, there has been a strong emphasis on interdisciplinary skill development within the tertiary education field and many resources are available within the primary education field, however there does appear to be a disproportionate lack of research within the secondary education field. Furthermore, how to implement, the capability of and potential benefits of interdisciplinary learning within high schools have been active areas of debate in educational research (Leonardo, 2004, Mergendoller, Maxwell, & Bellisimo, 2000, Schoenfeld, 2004, Spelt et al., 2009). Therefore, the systematic review required not just the presence of education but also a derivative of secondary or high-school education.

The aim of this review is to inform educators and educational researchers within the high-school arena. However, the review does draw from international sources and as such the delineation between primary and secondary (or high school) is not always comparable. This is particularly relevant in terms of "middle schools" which can range, depending on their locality, from Grades 6-8. Therefore, because of the varied "cut -off" for what is considered "middle school" this was also included in our SW. Subsequent screening removed those that did not constitute a comparable school year to that of a government High-school in Australia. This was achieved by comparing the grades of a middle year and the origin of the study. However, doing so should not detract from the international applicability of the findings of the systematic review. This was done simply to provide comparability across what could be considered a secondary or high school sector globally.

Before searching the literature, the following inclusion/Exclusion criteria were formulated:

- **IC1.** Selected publication was required to be relevant to the questions driving the systematic review, meaning that the publication should examine teaching and learning within the interdisciplinary framework as described above and provide evidence-based support for statements made within;
- **IC2.** Each publication was required to be peer-reviewed;
- **IC3.** The publication was written in English;
- **IC4.** The time span of the literature search was limited to 1990-2018 to provide the broadest overview of the research.

Three criteria for exclusion (EC) articles were also identified:

- **EC1**. Focuses on learning that does not meet the definition of interdisciplinary learning as described by Spelt et al. (2009). Of note here is multidisciplinary learning that involved the presentation of multiple perspectives without integration;
- **EC2**. Article does not provide an assessment of student learning which highlights an improvement in student learning outcomes compared to traditional pedagogical methods. If an article presented only theoretical conceptualizations, then it was excluded;
- **EC3**. The article was considered out of context, addressing an area not relevant to the research objectives.

While the comparable assessments required EC2 may be considered difficult to obtain, i.e. comparison of a "silo" based learning experience with that of an interdisciplinary one, there are several different methods that can be utilised to achieve this. These include the use of "content" specific to disciplines covered in both approaches, external assessments such as state-wide assessments, and ongoing participation in the STEM fields.

The IC and EC were implemented in the preliminary screening process. This involved examination of the title, abstract and keywords to ensure the selected articles fitted within the research focus of the study. Where a decision could not be made, or some ambiguity remained on whether the article was a valid selection, the article was included as it was deemed the full-text screening stage would clarify whether it should be included or not. When an abstract was not included in the text, the introduction was examined.

3 Review of the preliminary search

The systematic review was undertaken on 20/7/2018-20/01/2021. It is worth noting that the clear majority of articles were identified via the ERIC database, while most of the other selected databases yield no articles. Figure 1 shows the breakdown of the review and subsequent screening process via the PRISMA flow chart (Moher et al., 2009).

A total of 428 articles were identified based on this preliminary search (442 articles were identified by the PROQUEST database via ERIC search, which automatically excluded 14 articles as duplicates). Two articles were also identified within the Scopus database search. Three articles had been identified previously in the prior-conducted literature review; however, these articles were then excluded during the removal of duplicates, having also been identified in the ERIC search. There were no other duplicates identified other than the ones previously noted by the ERIC/PROQUEST database.

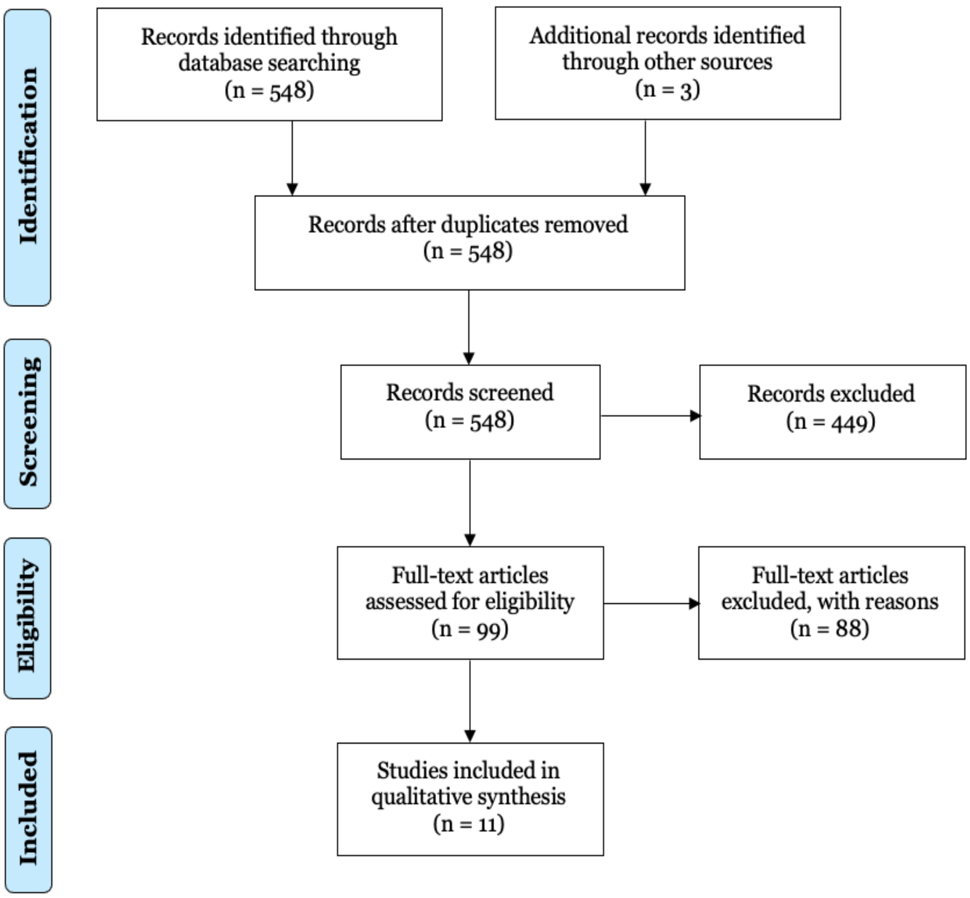

Figure 1. Modified PRISMA Flow Diagram (Moher et al., 2009)

4 Identification and selection of relevant research (Screening)

Upon preliminary screening of the original 548 articles identified, only 99 articles were found to fit the inclusion and exclusion criteria. All these articles, except 2 pre-identified articles, were identified within the ERIC/PROQUEST search. For each of these articles, the full text was examined, with regard once more to the EC and IC. The selection or removal of articles and the reason for is summarised in Table 4. It should be noted that an article only had to meet one of the exclusion criteria to be removed and only the first EC identified is listed, so it is possible that some articles would have been excluded under several criteria.

Table 4. Identification and selection of relevant research (Exclusion criteria)

Exclusion criteria	***No. of articles removed***
EC1: Focuses on learning that does not meet the definition of interdisciplinary learning as described by Spelt et al. (2009), of note here is multidisciplinary learning involving the presentation of multiple perspectives with integration	6
EC2: Article does not provide an assessment of student learning which highlights an improvement in student academic outcomes compared to traditional pedagogical methods. If an article presented only theoretical conceptualisation, then it was excluded	56
EC3: The article was considered out of context, addressing an area of not relevant to the research objectives	26
Total articles excluded	88
Total articles included	11

During the full-text screening of each of these articles, 88 articles were removed based on the EC. Consequently, the total number of articles to inform the data synthesis and discussion was eleven. It was worth noting that the majority of the excluded articles were due to a lack of direct comparison of assessment supporting the academic benefits of interdisciplinary learning. While they often provided evidence of interdisciplinary lessons, they either did not provide evidence of learning assessment, or some merely remarked on improvements but did not provide a comparison. Alternatively, they would show there was an improvement after the implementation but with no comparison to traditional educational methods, and consequently, it was not clear that the use of the interdisciplinary learning paradigm represented a distinct improvement over the traditional paradigms. As this was the criticism about the state of the field that inspired this study, it is not surprising that there were so few studies that fit this criterion. In addition, it has been suggested that it may be difficult to assess interdisciplinary learning as most existing assessment models focus on the content of a single discipline and therefore do not lend themselves readily to direct comparison (Honey, Pearson, & Schweingruber, 2014).

The second-largest number of articles excluded were due to EC 3, which addresses the need for the article to have a focus on the specific area of interest for this review. While many articles excluded due to this criterion were within the educational realm of interdisciplinary learning, they often focused on teacher perceptions or the capability of the material.

5 Data synthesis and discussion

Eleven articles were as such identified as being relevant to the systematic review research questions and fitting the EC and IC. Each of these eleven articles is outlined in detail in Table 5.

5.1 What empirical evidence exists that an interdisciplinary learning platform allows for greater learning outcomes for high-school students?

The overarching theme identified from the relevant eleven articles was that implementing a curricular change that encouraged interdisciplinary learning (or a derivative) resulted in not only higher academic success (compared to student learning within traditional silo style disciplinary education) but also enhanced motivation for learning and problem solving and capacity for complex understanding. This could be considered as evidence for some of the broad claims made by proponents of this pedagogical approach. One interesting finding was that of Yaki et al. (2019) which suggested the use of integrated STEM teaching resulted in improved student outcomes irrespective of the students' ability in science.

Table 5. Identified relevant articles for data synthesis

No	***Article***	***Description***	***Student outcome***
1.	Anderson (2010)	Project-based learning, collaborative work with community and other students within the automotive program. Students participated in a blended curriculum of core academic and content specific to the career field.	The program has resulted in the school being awarded numerous awards in the state, and a national skills USA competition.
2.	Inoa et al. (2014)	274 Year 6 and 7 students participated in culturally situated learning, utilising multi-modal and trans-mediated strategies. A multi-stage cluster randomised design was used to evaluate infusing process drama into a traditional language arts curriculum.	Students in the integrated classes outperformed the control (373 students) in both maths and language arts.
3.	Vahey et al. (2012)	Seventh grade students participated in a working-with-data project. This consisted of enhancing data literacy through an integrated curriculum of social studies, mathematics, science and English.	The students within the program showed higher skills in data literacy and core discipline-based content compared to control groups.
4.	Ferrero (2006)	Centred on a student-centred instructional model focusing on a combination of test preparation, traditional content teaching, and collaboratively developed thematic projects.	Students from grades 9-12 within the program showed both improvements and increased participation in the ACT's EXPLORE test, a readiness assessment test, which is part of a program to measure skills development through high school. 10th and 11th grade improvements exceeded predicted growth by 71 percent.
5.	Schuchardt and Schunn (2016)	Year 9 and 10 students were taught using integrated STEM pedagogy and compared to students taught using traditional methods.	The students showed improved complex mathematical problem-solving skills and understanding of mathematically modelling processes.
6.	Hendry, Hays, Challinor and Lynch (2017)	Students in grades 9-12 participated in project-based learning via multidisciplinary projects.	State-wide standardised exit exams showed improvements compared to previous years and other schools with above state average scores in all subjects.
7.	Greenes et al. (2011)	Long-term problem, project-based and collaborative learning within a "Scientific village" paradigm with teachers, STEM professionals and 33	The results showed that students attempted and completed more advanced relevant courses in high-school

		high-school students on 10 projects. The students were matched to a control group and later tested on interest in and academic success in mathematics and science.	and expressed desires to explore STEM related careers.
8	Stryf et al. (2019)	Observational comparisons on grade 9 Mathematics, Physics and Integrated STEM classes.	Students in Integrated STEM classes showed higher levels of engagement compared to more traditional classes.
9	Huri & Karpudewan (2019)	Integrated STEM lab activities were utilised to improve understanding of electrolysis. Pre- and Post-test analysis and interviews were utilised to test effectiveness of Integrated STEM as a learning platform.	Integrated STEM-lab activities explained 33.6% of the improvements in understanding of Electrolysis. Interviews supported this finding.
10	Yaki et al. (2019)	Grade 11 students were either taught a genetics module via an Integrated STEM or traditional pedagogy.	Students taught using Integrated STEM exhibited significantly higher improvements in terms of a comparison of Pre- and Post-test data collected via a 40- multiple choice examination.
11	Condon & Wichowsky (2018)	Grade 7 and 8 Students were either taught an integrated STEM/civic program (STEMhero) or traditional science instructions	Students in the STEMhero curriculum showed increased engagement in Science, maths and civics and desire to continue with maths and science.

5.2 What pedagogies are supported by empirical evidence for the successful implementation of an interdisciplinary learning platform?

Across the eleven studies reported here, there were a number of themes that consolidate into three key methodological aspects that form an evidence-informed protocol for the implementation of interdisciplinary learning in the high-school education sector.

Firstly, all the studies utilised either a project- or problem-based learning platform. Project-based learning, and to a lesser extent problem-based learning (Schucardt & Schunn 2015), is considered an approach that provides students with an opportunity to "learn by doing" (Anderson, 2010; Greenes et al. 2011; Hendry et al., 2017) such as completing a lab activity on electrolysis to improve the understanding of the processes involved (Huri and Karpudewan, 2019). As both names suggest, while having their own distinct features, they centred around complex, often multi-stepped tasks, with strong student-centred involvement and provides opportunities for authentic learning and experiences (Anderson, 2010; Barron et al., 1998; Savery, 2015; Struyf et al., 2019; Thomas, 2000). It should be noted that one study, Condon and Wichowsky (2019) identified their approach as inquiry-based learning; however, the description of the implementation overlaps many of the aspects discussed in problem and project based. Secondly, these projects or problems were aligned with real-world aspects (Anderson, 2010; Condon & Wichowsky, 2019; Hendry et al. 2017). This gave the students some context to the content they were learning and potentially led to the improved attitude towards educational experiences described (Ferrero 2006; Greenes et al. 2011). As quoted by one student "I feel like I'm getting a life skill, something I can use outside of any test" (Ferrero 2006, p. 8). In addition, several of the studies identified improvements in key indicators of student attitude, such as completion, attendance and interest in pursuing STEM-related careers. Considering that the decline in STEM-related workforce and population STEM literacy and capabilities were the concerns that prompted the original emphasis on STEM, such a finding is particularly noteworthy. Thirdly, many of the studies emphasised the use of collaboration and community involvement. For example, Greenes et al. (2011) relied heavily on the use of STEM professionals within their scientific 'villages'. Beyond simply increasing the pool of professional knowledge available to the students (Anderson, 2010), this was also found to provide exposure to STEM careers for the students as well as providing data and resources for the projects (Anderson, 2010). Furthermore, utilising the services of such professionals provided the students with exposure to individuals who have already achieved interdisciplinary thinking– a skill that the literature suggests may need refinement as well in the teaching community, who have been trained to work within distinct silo style disciplines (El-Deghaidy et al., 2017; Hasni et al., 2015; Stubbs & Myers, 2016; Wells, 2011).

However, it is important to emphasise that while 548 articles were identified as addressing interdisciplinary learning, and 99 passed the EC and IC, albeit on the basis of reading the abstract, it was only eleven articles that provided empirical evidence of greater learning outcomes by the students. This would suggest that while student centred project and problem-based learning platforms are an excellent starting point for refining the methodology for an implementation of interdisciplinary learning, there is still a strong need for additional research into the impact on students.

One interesting finding from this systematic review was that many of the studies documented utilised either pre-existing standardised testing or assessments developed for a silo-based education system. While even within this paradigm the use of interdisciplinary pedagogy did still show a marked improvement, it does also leave the potential for other benefits unexplored. For example, one of the main critiques of teaching using a traditional "disciplines as silo" style is that it leaves students unprepared for dealing with the "real world" where disciplinary boundaries are less distinct. In comparison, one of the key benefits of interdisciplinary learning was that students were able to make connections between these disciplines when solving problems or developing projects. While discussed, this was rarely comparatively assessed within the studies identified above. Hendry et al. (2017) did identify this discrepancy and discussed some of the options available to address it. Of course, while creating a fair assessment for identifying links between disciplines to compare the outcomes of silo and interdisciplinary education may be difficult, it is worth noting that this and other benefits that an interdisciplinary approach could conceivably achieve may not have been identified in this systematic review.

6 Conclusion

The findings of this systematic review support the proposition that the implementation of STEM/STEAM as a platform for interdisciplinary learning does result in higher results in assessed learning outcomes (RQ1) such as greater results in comparable testing, awards and participation in relevant academic pursuits. In addition, such a platform can potentially enhance a range of other outcomes not measured by traditional means. These include greater alignment of teaching and learning to real-world contexts, increased student collaboration, as well as opportunities for community involvement and interaction with professionals employed in STEM-related careers who are more likely to be interdisciplinary minded. The common educational threads for the successful implementation (RQ2) the use of project/problem-based learning and community collaboration and involvement.

In summary, whilst research into the appropriate guidelines for implementation is still in its infancy and further rigorous studies similar to the eleven identified are required, this preliminary research points towards a strong reliance on project or problem-based learning pedagogy with the use of community and collaboration both between students and the greater community.

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Promoting STEAM learning in the early years: "Pequeños Científicos" Program

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Education in the early years is an excellent space for promoting integrated learning. The STEAM education model combines Science, Technology, Engineering, Arts and Mathematics holistically and has gained force globally, mostly in developed countries. However, in developing countries of Latin America, STEAM education programs are incipient and still unfamiliar to many early childhood and primary school educators. "Pequeños Científicos" is a pioneer educational program in Chile aimed at providing extracurricular academic enrichment to students 3 to 10 years old, with a gender-empowering approach. With a cross-sectional design and integrating data from students, researchers and educators, this article documents program design and implementation issues based on a partial application of SWOT analysis grounded on strengths, weaknesses and opportunities. The strengths were identified the strongest elements that might be transferred to similar interventions, for instance, students were positively engaged in the learning processes and actively communicating their advances through diverse artistic formats. The weaknesses were mainly difficulties that can be prevented in future replication, such as teachers' management of children's behavior. Opportunities present alternatives to these types of programs to improve and grow; for example, through articulation of the courses and including children with additional needs. We call for tackling the weaknesses for more efficient application and discuss the promotion of STEAM learning in the early years in the contexts of high educational inequality for future replication in diverse contexts.

Keywords: STEAM, learning, early childhood education, gender

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1 Introduction

In the past decades, educators' and scientists' interest in early science learning has increased dramatically (Sharapan, 2012; DeJarnette, 2018). Pre-school children have a natural inclination toward science due to their sense of curiosity and ability to find solutions based on creativity and imagination (DeJarnette, 2018). Indeed, young learners can be engaged in scientific practices such as conducting investigations, observing diverse elements of nature and inferring patterns and regularities, or explaining the causes of natural phenomena (Legare & Gelman, 2014).

In this regard, STEM (Science, Technology, Engineering and Mathematics) education has spread globally, especially in developed countries in which critical relevance has been given to facilitate children's future success (Akturk & Demircan, 2017). However, in developing countries of Latin America, it is incipient and mainly focuses on secondary education, perhaps due to promoting interest in scientific careers or reducing gender inequalities (García-Holgado, Camacho, & García-Peñalvo, 2019). Consequently, evidence from STEAM programs comes mostly from developed countries. Further, it is relevant to incorporate STEAM programs oriented toward young children in diverse countries to advance educational opportunities, especially in areas with marked gender inequalities.

Our study focuses in the "*Pequeños Científicos*", a pioneer educational program in Chile aimed at providing extracurricular integrated courses to students 3 to 10 years old based on their interests by age, with a gender-empowering approach.

Given the centrality of research abilities for learning through life (UNESCO, 2015), it is crucial to infuse interest in and expose learners to scientific practice in their early years. STEAM integrates and uses the arts in the STEM curricula to construct knowledge and help children express concepts (Piro, 2010). Taking into consideration that arts are vital in early childhood education, combining STEM with arts, it is likely to engage teachers to develop and implement activities oriented to these areas (Sharapan, 2012). Following Sharapan's (2012) line of thinking, in the present study, we considered STEAM components as disciplinary areas with equal importance. For early childhood education, we understand each element as follows (Sharapan, 2012, p.37).

> Science. Science is about nurturing a sense of wonder and curiosity. It's about experimenting, encouraging investigation, and asking 'Why do you think...?' questions. In early childhood, science is about everyday experiences, like what makes shadows, how plants grow, why ice melts, and where different animals live and what they eat. When children tell you their idea of why something happens, that's a hypothesis!
>
> Technology. Technology is just a fancy word for tools. Adults tend to think of technology as digital equipment like cameras and computers or sophisticated machines in factories. But crayons and pencils are tools. So are rulers, magnifying glasses, scissors, zippers, and even dump trucks.
>
> Engineering. Engineering starts with identifying a problem, then moves ahead to thinking about solutions and trying them out. All of us have seen children go through these processes when they're trying to figure out how to make a strong foundation so they can build their blocks higher or when they're working on a toy boat that will float in the water table or making a stable base so their clay figures stand up.
>
> Art. Adding the arts gives children the opportunity to illustrate STEM concepts in creative and imaginative ways, express ideas about the world through music and

dance, communicate with descriptive language, illustrate ideas with crayons or markers, create graphs, and build models.

Math. Mathematics is much more than counting. Mathematical thinking includes comparing, sorting, working with patterns, and identifying shapes. Language, too, plays a big part in math, for example, when we use comparison words like bigger, smaller, higher, lower, farther, and closer. Higher-level math thinking comes into play when we help children know that comparisons are relative.

Since an important objective of early education is that students gain a deeper understanding and practice using logic and evidence for reasoning about the natural world, STEAM educational contexts are suitable spaces to promote integrated learning. Further, teachers and educators are in an optimal position to connect early childhood learning experiences with the subsequent academic learning objectives and accomplish the goal of education beyond the specificities of separate disciplines (DeJarnette, 2018; Çiftçi, Topçu, & Foulk, 2020). Indeed, it has been documented that the reception of integrated STEAM lessons by pre-school children shows high levels of engagement and cooperation. Thus, it is crucial to increase the positive exposures and experiences related to these subject fields both for students and their teachers (Aronin & Floyd, 2013).

2 STEAM in the early years: Challenges faced by teachers

2.1 Engaging students in scientific practices

One of the challenges for educators designing STEAM experiences is engaging students in more authentic scientific practices. These include observing, experimenting, or carrying out scientific investigations and communicating ideas, discussing the evidence that supports these ideas with peers, and supporting metacognitive operations (Crawford and Capps, 2018). Research has shown that enhancing children's natural curiosity, and providing positive childhood experiences with enjoyable science, and encouraging family educational involvement plays an important role in learning outcomes (McClure, 2017; Monkevinciene, 2020). In fact, this is especially relevant knowing that parents can support or hinder their children's STEM education. Indeed, parents might hold negative attitudes about STEM or have limited STEM knowledge to support they children, thus, perhaps they limit the chances for children's learning in these disciplines (Milner-Bolotin & Marotto, 2018).

2.2 Building on children's interests

Another challenge is expanding children's natural learning interests by integrating them with areas of teaching. This purpose might be a problem if teachers are constrained by educational curricula based on excessive content rather than learning the processes (Cabello & Ferk Savec, 2018). Teachers can overcome this issue by integrating STEAM learning into everyday moments (Sharapan, 2012), student hobbies (Dabney, Chakraverty, & Tai, 2013) and student-posed questions (McClure, 2017; Sharapan, 2012), focusing on local phenomena (Lee, 2020), as well as using interactive technology such as labs (Proudfoot & Kebritchi, 2017). Nonetheless, critical positioning regarding technology and children's motivation is needed, not to assume that technological tools motivate students by default but considering the pedagogical intentions and ways of interaction technology might facilitate in the learning settings.

2.3 Dealing with STEM gender stereotypes

The gender gap is pronounced in STEM fields, but it is larger in computer science, engineering, and physics than in biology, chemistry, and mathematics (Cheryan et al., 2017). In some regions, such as Latin America where the present study takes place, it is particularly pervasive because of cultural norms that influence female behavior (García-Holgado, Camacho, & García-Peñalvo, 2019), and social stereotyping that discourage women from being interested in STEM learning, pursuing science or mathematics activities or professional careers (García-Peñalvo, 2019). Indeed, it is a challenge for teachers to consider elements of gender equity within the design of courses (MacDonald et al., 2020). As a result, partly explained by gender stereotypes operating early in pre-school (Beede et al., 2011; Bordón, Canals, & Mizala, 2020; Savinskaya, 2017), women are a minority in STEM areas at the university level. Nonetheless, teachers can influence the interest of young girls in learning these areas (Fadigan & Hammrich, 2004). Indeed, the gender of the teacher has a significant impact in modeling the role of women in STEM (García-Holgado, Camacho, & García-Peñalvo, 2019; Chen, Sonnert, and Sadler, 2020; Jeong et al., 2019). Though short time role model interventions in childhood sometimes change stereotypical beliefs about women but not necessarily shift the young girls perceive themselves regarding STEM disciplines (Olsson & Martiny, 2018).

3 Teachers' experiences with STEAM-STEM in the early years

STEM might be an unfamiliar term for many childhood educators (Sánchez Lozano & Casallas Ochoa, 2020) and confusing when applied to pre-school teaching (Moomaw & Davis, 2010). As it was previously mentioned, in the present study, we include the arts in the acronym because of its relevance for the early years' education. We define STEAM as an interdisciplinary approach integrating holistically the development of knowledge and skills in science, technology, engineering, arts and mathematics education (Monkeviciene et al., 2020).

Notwithstanding teachers' general positive beliefs and attitudes towards STEAM for young learners when they get to know integrated learning experiences, certain hesitation to implement activities in the classroom may be apparent due to lack of teachers' STEM content knowledge, feeling unprepared to teach, or uncomfortable to address concepts in these integrated science-related fields (Nesmith & Cooper, 2019; Sharapan, 2012). Some other barriers that educators often encounter are poor parental and school support, lack of technological resources, difficulties to use STEAM approach in a practical way with children (Ogegbo, & Aina, 2020), or insufficient experiences with the elements of the engineering process for young learners (Nesmith & Cooper, 2019).

Nonetheless, research has shown that with proper professional development, efficient and contextually relevant, early childhood educators and teachers are able to implement successful practices based on STEM or STEAM, or to do so more confidently (Brenneman et al., 2019; Çiftçi, Topçu & Foulk, 2020; Monkeviciene et al., 2020; Simoncini, & Lasen, 2018).

Teachers who have participated in STEM or STEAM professional learning experiences, gain confidence and perceive themselves to become more efficient in implementing these kinds of strategies in early childhood education (Nesmith & Cooper, 2019). Further, teachers' understanding of the advantages of incorporating these disciplines in early education is increased when they combine arts with STEM disciplines (Lawson et al., 2018). Indeed, STEM disciplines are being implemented in many contexts at the pre-school level with diverse emphases and results, taking arts as a standing point. Thus, in those positive conditions, STEM activities provide an effective platform for rich learning experiences (Brenneman et al., 2019). However, in early childhood education, creating opportunities for children to learn in a real, integral and meaningful context is needed (Sharapan, 2012). The role of arts in the creation of new knowledge, opening experiences to children exploration with materialities and allowing expression of students learning is essential in pre-school and primary education alternatives (Monkeviciene et al., 2020).

3.1 Study Context

Our study centers on *Pequeños Científicos*, an extracurricular educational enrichment program in Chile launched at a university-based Centre for the Development and Education of Talents, PENTA UC. It is aimed at students 3 to 10 years old and seeks to nurture their curiosity, inquiry, and positive attitudes towards learning while promoting XXI century skills such as creativity, problem-solving and systemic thinking. The latter is in line with the international trends that have positioned the integrated STEAM areas as a core part of future educational models. The program is offered twice per year (summer and winter intersessions) at the Pontificia Universidad Católica de Chile campus facilities. It is a week-long program where the students meet teachers for 4 hours every day of the week (20 hours total), complemented by a learning exhibition with families at the end of the week. During its five years of implementation, the program has reached hundreds of students with courses designed and taught by scholars, researchers, and educators. The innovation documented in this article embeds the arts within STEM, and explicitly promotes a gender-empowering approach. Instead of a disciplinary emphasis, courses have the integrated STEAM focus and enhance the critical role of women in the development of each discipline. This approach also includes elements of the nature of science afforded by the courses through hands-on inquiry and modeling-based learning.

The study documented here aims at answering the following research question:

What are the most significant strengths, weaknesses, and opportunities embedded in the design and playing a key role in the implementation of STEAM education for young children in the Pequeños Científicos program?

The purpose of the study is to document the design and implementation of a university-based program to promote STEAM learning in the early years and to discuss aspects for future replication. The presentation analyses issues that the program implementation raises regarding the application of the STEAM approach in early education in contexts of marked gender and educational inequality, based on a partial application of SWOT analysis grounded on strengths, weaknesses and opportunities. Results are expected to inform future replication of STEAM programs such as this one, in the contexts of inequalities and disadvantages, thus offering hope to the countries that do not count with advanced educational development. This is relevant for the educational community beyond the specific program and it illustrates that university teachers might interlock the learning needs of children in STEAM areas with their own interests to spread their knowledge to the younger learners, which is part of the novel contribution of this work.

4 Research Methods

4.1 Study design

The study had a cross-sectional design, anchored in the contextual features of the program implementation. The approach was observational in nature and oriented to capture the process at a single moment in time. We followed the guidelines of action-research, which commits not only to researching a phenomenon but proposing actions oriented to improving or transforming the experience of the study participants (Efron & Ravid, 2019). The scope was descriptive and integral, considering perceptions of the program's participants by combining student, researcher, teacher, and teaching assistants' views. In line with a participatory research paradigm (Bergold & Thomas, 2012), the epistemological belief that supports this decision is that every participant in a program has a unique and valuable perspective on the strengths and weaknesses of the program. The analytical strategy was mainly based on qualitative data of the information gathered, complemented by a sequential quantitative measurement. Thus, the study can be considered a multi-method approach with qualitative predominance with an evaluative purpose.

4.2 STEAM learning in the context of the Pequeños Científicos program

Pequeños Científicos puts the child at the center of the learning process, providing opportunities to choose the courses to enroll in. Likewise, keeping the classes small - between 10 and 17 participants, with one teacher and two teaching assistants is a crucial characteristic of the program, towards for favoring personalized interactions. The program consists of one-week courses delivered at the university; each student chooses two courses to enroll in. The description of the courses offered as part of the *Pequeños Científicos* program in 2020 is presented in Table 1.

The teachers of the courses are experts and researchers in their academic fields and were willing to teach their discipline in connection with the STEAM areas. The teachers usually work as academics in faculties of Sciences, Arts, Mathematics, and Education. Teaching assistants are undergraduate student teachers from the STEAM areas, coming from the Faculty of Education or PentaUC alumni. Teacher and teaching assistants have on-site training, which includes an initial organizational meeting and small groups' meetings for a thorough review of the course plan and articulations between courses within each age level; ages 3-4, 5-6, 7-8, and 9-10.

As characterized by their parents, children who attend the *Pequeños Científicos* program are fast learners in the disciplinary area they like the most; they usually get bored in their school lessons as oftentimes these do not provide optimal learning opportunities. Further, occasionally, these young learners have been labeled as behaviorally disruptive in their regular schools.

To monitor implementation, the program coordination team conducted several lesson observations during the week. At the end of the week, children, parents and teachers share their achievements and products in a learning exhibit.

Though course lesson teaching strategies reflect teacher's own style. All courses shared the following guidelines, which show the program ambitions:

- Authentic disciplinary learning methodologies including questions, problems, or solutions relevant to the disciplines.
- Children are exposed to exploratory activities and also expressive actions. This point means that they receive information and are encouraged to create products such as posters, expositions, explanations, artwork, etc.
- Teachers promote peer learning throughout the activities.
- By linking university experts with students from different educational contexts, both students and teachers learn from each other.

For the year 2020, the team decided to impart the program ~~courses~~ with a gender-empowering approach that materialized in the subsequent decisions. First, the process of teacher selection prioritized inspiring and charismatic women to favor the role-modeling of brilliant female researchers in their field. Second, each course highlighted the role of a woman in the history and development of each of the STEAM disciplines. Third, the difficulties faced, and the contributions of each iconic woman were explored through productive discussions and compared with the situation of women in the disciplinary fields nowadays. Finally, the program coordination team reviewed each course's plan -including the skills, content, materials, activities, and budget- to ensure coherence among the courses. The list of courses with the focus described above is presented in Table 1, while Table 2 presents examples of the teachers' questions that guided students' explorations.

Table 1. List of courses offered as part of the Pequeños Científicos program in 2020

Age group	Course	Description of the purpose	Contents	Methodology
3 - 4	Materials of my environment I	To explore fundamental properties of materials available in the environment, an inquiry-based approach aimed at developing scientific thinking skills; comparisons and classification	Stiffness and flexibility of diverse materials	Guided inquiry, communication through artwork.
3 - 4	Little science	To explore and experiment with diverse artistic materials and technologies to provoke curiosity and pose questions about daily life science.	Environment and biodiversity, plant life cycle, solar system, magnetic field	Experimentation, story analysis, group artwork
5 - 6	Paleo-artists	To develop the creativity and artistic skills to imagine the prehistoric world and, subsequently, enrich the ideas through scientific evidence.	History of science with themes of paleontology and geology; sediments and fossils, dinosaurs and mammals of the Cenozoic	Experimentation, drawing, and sculpture techniques
5 - 6	Materials of my environment II	To explore and communicate the mechanical properties of materials, relating them to their possible uses in everyday life. To design experimental situations to explain the materials' changes when applying force, heat, or water.	transparency / opacity, flexibility / stiffness, roughness / smoothness of diverse materials	Guided inquiry and experimentation, artistic communication through models, posters, and drawing
5 - 6	Microorganisms: heroes and villains	To design ways and prepare simple cell culture preparation to know microorganisms beneficial and harmful for humans, plants, and animals.	Definition and characteristics of microorganisms; types of microorganisms -bacteria, fungi, and viruses-; beneficial and harmful microorganisms for humans, plants	Guided inquiry and experimentation, artistic communication through painting
5 - 6	Astro-girls and Astro-boys	To explore introductory astronomy through technology and arts using astrophotography, simulations of other solar systems, and music created from orbit patterns and planet movements.	Formation of the Universe, the Solar system, other planetary systems, and exoplanets. Types of stars according to size and temperature, evolution and stellar death -supernovae, hypernova, and black holes-.	Observation of animated stories, augmented reality, artistic presentation in diverse formats

7 - 8	A trip from the Universe to the Earth Center	To develop scientific thinking skills such as hypothesizing about Earth's structure through learning mediated by technology.	Cosmo-vision, the Earth in the solar system, layers of the Earth, earthquakes, tsunamis, and volcanic eruptions	Guided inquiry, analysis of the history of science through story tales
7 - 8	Let's construct a science, art, and technology project!	To build innovative and creative projects to better relate to the people and living things around us, such as animals and plants. The projects are based on artistic work and the use of technology.	Steps to build a science, art, and technology project	Project-based learning with artistic communication - theater, comics, and photomontages-.
7 - 8	Researching with my senses	To put the senses to the test by exploring simple materials, collecting and analyzing data, and finally, representing them mathematically.	Where are the sensory systems located, and how do they work?	Guided inquiry, artistic presentation in diverse formats
7 - 8	Mysteries of water	To observe the characteristics of fluids and apply their different facets to elaborating artistic or technological projects.	Water properties; immiscibility, buoyancy, density, fluidity, capillarity, surface tension	Guided inquiry, experimentation with technologies
9 - 10	Illustrating science	To develop scientific illustration, a scientific - artistic discipline promotes learning through direct observation, drawing, and documentation.	Environmental awareness, ecosystem, needs of native plants their roots, stem and leaves, the life cycle of flowering plants	Project-based learning, drawing, and painting techniques
9 - 10	Physics-Chemistry of the living being	To apply science to solve daily life problems related to osmosis, photosynthesis, and digestion.	Differentiation between physical and chemical change, photosynthesis - reactants and products-, digestion and osmosis	Experimentation and communication: presentations and artistic posters
9 - 10	How does my bodywork?	To discover curiosities about body functions and make informed decisions regarding the care and integrity of their bodies.	Musculoskeletal, nervous, digestive, circulatory, and respiratory systems	Guided inquiry, experimentation, and models construction
9 - 10	Eclipse hunters	To understand solar eclipses' phenomenon through the artistic design of a dark box to model the phenomenon.	Rectilinear propagation of light, angular size, conditions for a solar eclipse, the arts in astronomy work	Modeling of phenomena through software

Table 2. Examples of teachers' questions that guided students' exploration

Course	**Activity or contents**	**Examples of teachers' questions – mediations**
Materials of my environment I	Characteristics of some insects' wings. Activity: Wings, Little wings, so light! The students answer teachers' questions to gather their prior knowledge. Then they observe a video with a simulation of butterfly wings movement in flight. Finally, they construct a model of the wings choosing the materials and their characteristics.	Do you know butterflies? Have you seen a butterfly flying? Where? Do you like them? Are you afraid of butterflies? How do you think there are butterfly wings? After the video: If we had to create wings similar to butterflies' wings, what materials would you use for the wings? And the butterfly body? Why? Which materials' characteristics would you have to look for? Why? Now we will build a model with the materials you have chosen.
Astro-girls and Astro-boys	Activity: To construct a scale model of the solar system and a black hole's hypothetical model. The students answered teachers' questions to gather their prior knowledge, and a productive group discussion was conducted after the construction of models.	How do you think the Universe was formed? What do you think is the size of the Universe? And its form? What questions do you have about the Universe? After constructing the models: Do you think we can observe the sun and black holes directly? Why? Do you think the stars and planets are immortal?
A trip from the Universe to the Earth Center	Activity: the students observed animated stories of famous scientists Alfred Wegner and Inge Lemann. They start a productive discussion guided by teachers' questions.	How was the scientific knowledge constructed in the time of Alfred Wegner and Inge Lemann? What the shreds of evidence to pose the ideas of Wegner and Lemann were? Why were both scientists not reasonably recognized in their trajectory? Similarities and differences?
	Activity: The students explore through augmented reality two simulations of phenomena: earthquakes and volcano eruptions. Then they answer in groups teachers' questions.	What did you observe in the simulation? What elements did you not know about these two phenomena? Why do you think these phenomena are caused? Which is the role of technology in scientific phenomena comprehension?

4.3 Ethical procedures

We followed the ethical guidelines to collect, process, and protect the data gathered in this research; anonymity, confidentiality, and the use of secure storage and controlled access to the data sets. In our data processes, none of the participants' names or identities were revealed. We assigned numbers to each participant and cover their names on the paper or artwork to ensure anonymity in the datasets. Moreover, in our study, the participants were voluntary. All parents signed an informed consent with detailed information about the program, students permitted to use their data for research purposes, and the teachers gave authorization to take notes during focus group meetings and use the information contained in the logs and summary sheets for evaluation and investigation purposes. If the students or another participant did not agree to participate in the study, the learning opportunities were offered, but their data were not considered in the analysis. In the same line, if a participant resigned the will of taking part in the study, information was separated from the dataset and not analyzed. To maintain confidentiality, only the research team had access to the data. The information was kept in a safe office and backed-up in a cloud with a password to assure controlled access and data protection.

4.4 Sample

Ninety-five students participated in the pilot version of the program in January 2020, which was under evaluation. Based on their age range and their interest in the courses, students were divided into six different groups. The academic body was composed of 10 teachers and 12 teaching assistants. The teachers, teaching assistants, parents, and students were aware of this version of the program's evaluative character. Thus, they knew beforehand that some lessons would be observed, some student products would be collected, and that teachers and teaching assistants would be invited to participate in group discussions at the end of the program implementation.

4.5 Assessment instruments for data collection

For children, we looked for validated scales to measure attitudes towards STEAM in Spanish language which was the first language of the students. However, in the literature reported so far and to the knowledge of the authors, the instruments with open access were oriented to each discipline separately. Thus, we decided to use a more general instrument regarding science than several instruments, to avoid overloading the students.

Hence, an adapted version of Gómez-Motilla & Ruiz-Gallardo's (2016) attitude survey to assess attitudes towards science in early childhood education for the Spanish speaking population was administered as a pilot test to one course of 7-8 years old's, representing 17 participants. The survey was applied at two points in time, before the first lesson started and again after the last lesson. Most original scale items were kept, but the 5-point Likert scale response format was simplified to three-points: totally agree/ neither agree or disagree / totally disagree. Moreover, we added emoticons with a happy face, neutral face, an angry face to represent the options (details can be seen in the Appendix). The teachers were instructed to read aloud each of the sentences and encourage students to paint, mark, use clay, or any other kind of material to express their response to the emoticons in front of each sentence. Survey items included ideas such as "Science is interesting," "I like to learn about science and technology," "Science and technology are good for life and useful," "All the students should learn these topics," and "I like talking about science with my family." This last question was particularly relevant as there is evidence that talking with friends and family about science during infancy is later predictive of a STEM identity (Dou et al., 2019) and that parents might serve as relevant sources to support STEM education (Milner-Bolotin & Marotto, 2018; Milner-Bolotin & Milner, 2017).

Researchers conducted also a non-participant observation in each course taught, using the regular class observation protocol of developed by the PentaUC program (in the Appendix). This instrument provides ratings of lesson structure, teaching methods, classroom interaction, and classroom climate, as well as learning assessment conducted by the teacher during the lesson. We decided to use this instrument because it was familiar for the coordination team, perhaps the implementation in this pilot version would be facilitated. No classroom recordings on video or audio were conducted, to fulfill children's data protection policy of the institution.

Teachers' and teaching assistants' views about this version of the program were collected through logs in the format of narratives, anecdotal records. This decision was taken considering the restricted time the teachers had to complete paperwork and the need to gather information for the research purposes and for the program monitoring at the same time. The log records of teachers and teaching assistants were collected both online and in paper-and-pencil through logs in the form of narratives and anecdotal records. Responses were included in the same pool of data to process all the data together. We obtained 44 logs from teaching assistants and 20 from teachers during the week of implementation.

To document the process of each course, teachers completed a written summary sheet with answers to the following questions:

1. Which were the main obstacles and advantages in the course implementation?
2. In your opinion, were the course objectives achieved? How could the course design be improved?

3. Did you need to make methodological adjustments to your course design? Why?
4. Do you have any other comments, suggestions, or relevant observations to mention?

At the end of the courses, focus groups with teachers and teaching assistants were organized into groups of 4-6 participants according to the age range of students. This means teacher and teacher assistants of children between 3-6 years old comprised a group, the ones of children between 7-8 years old in another group and so on. The guide questions were:

1. Which were the main obstacles and advantages in the course implementation for this age group?
2. How could articulation between courses improve course design?
3. Which methodologies were the most and less effective for this group?
4. Do you have any other comments, suggestions, or relevant observations to mention?

4.6 Data analysis

Qualitative analysis was chosen because of the nature of the information collected, mainly descriptions, observations and appreciations of the participants who conferred the meaning to the actions and interactions in the social phenomena (Cáceres, 2003). To avoid conflicts of interest, the qualitative coding was carried out by independent researchers who did not participate as teachers. The steps we followed for creating the codes were: i) pre-analysis, which implied the recognition and identification of concepts in the analysis units of each topic; ii) determination and definition of initial codes for each of the topics; and, finally iii) integration and establishment of the final categories to refine the analysis.

The analysis of the data followed a multiple-methods approach.

Responses to the group discussions were analyzed as vignettes and organized first into emergent themes with illustrative excerpts from the participants. Next, themes were connected within a frame of strengths, weaknesses and opportunities to pursue an integral evaluation of the program.

Similarly, teacher's log narratives were categorized into strengths, difficulties and opportunities, following the guidelines of content analysis (Krippendorff, 2004). Content analysis is "the research technique for making replicable and valid inferences from text (or other meaningful matter) to the context of their use" (Krippendorff, 2004, p.18). The steps followed were: a) To determine the object (the educators' narratives written in their daily logs) b) To define the coding rules organizing them from the most to the least frequent ideas in the material considering also those that were repeated between the different courses, c) To determine the categories (strengths, difficulties and opportunities for promoting STEAM in the early years through this program) d) To verify the system of coding and categorization, including the validation of the program director and checking the transparency of the codes through inter-rater agreement calculation, e) To generate the inferences.

The process of analysis was aided by the online software Dedoose (https://www.dedoose.com), a commonly used program for qualitative data that is suitable to integrating and reflecting on the information obtained from diverse sources transformed into texts (Talanquer, 2014). To validate the integration of the final codes and categories, a review was carried out by two expert judges on the subject of talent education and co-authors of this article. Estimated inter-rater levels of agreement were high, specifically at 80% for the categories and codes.

There was also a quantitative analysis of the data obtained in the student survey. The mean of each affirmation of the survey obtained was introduced into a spreadsheet. We used the SPSS statistical package (IBM Corp., 2010) for conducting a Student *t*-test, which is the most common statistical method for comparing means (Wilcox, 1992) within the traditional parametric tests for comparing normally distributed population (Siegel, 1956). This analysis was done to explore possible differences in the students' attitudes at the beginning and the end of the program.

5 Results

The student survey analysis illustrated that the group of participants had marked interests regarding science and technology, which was expected as they joined the program voluntarily, as was expressed by the agreement on sentences related to positive attitudes toward science in general and learning about science and technology. All the students marked a happy face in those sentences, which was an indicator of "I agree" (see the instrument in Appendix). However, less agreement was found in the question about the extent to which students like to talk with their families about these topics. No statistical differences were found in the pre and post-surveys.

The next section presents the main results, categorized as a) strengths, b) weaknesses, and c) opportunities for the program to develop by integrating information from the logs, summary sheets, discussions, and observations. These are organized from the most to least frequently mentioned by the participants.

5.1 Strengths

One of the most valued aspects of this pilot program on STEAM learning mentioned by participants was allowing young learners to view scientific work as an exciting endeavor. Researchers, teachers and teaching assistants noted that the students showed particular commitment to the construction of models in the lessons, during which they put hands-on learning into practice. The teachers observed enthusiasm in children and positive engagement working with diverse materials and settings.

> "The children begin the lesson designing a house, a model, using different materials. They were enthusiastic, these models will be shared on the last day in a learning exhibition with their parents".
> "The children worked in the Faculty yard, very engaged on making pastry and adding yeast to observe the reaction. They were committed later on to keep the pastry properties by holding it on a special paper to maintain a specific temperature".
> "The children presented a different disposition today since we have to carry out practical activities that are more of their interest."

A second strength of the program implementation was the integration of science with other disciplines. Students were immersed in enriched experiences, mostly provided by technology as part of STEAM education. We, as researchers, think this experience was novel and challenged some students' previous expectations of what constitutes science practice.

> "A facilitator was using technologies, as immersive audio and projector. In the beginning, we watched a star size comparison video, and the children liked it a lot. We had to play it three times! In the end, we asked them what they have learned, and several students answered the concept of 'exoplanet,' although they did not remember its name".
> "Students show great interest in working with tablets."
> "The use of audiovisual resources such as science videos were aspects that motivated the boys and girls a lot."
> "The topic worked arouses the interest of the children and the (integrated) way in which the session was carried out allowed them to participate actively, asking questions and sharing their knowledge."

In sum, the integration of STEAM disciplines was crucial for promoting young learners' interests and enhancing engagement and motivation for learning in an amalgamated way, going beyond each discipline's particularities.

A third perceived strength was the high enthusiasm displayed by teachers and teaching assistants. Together, they constructed nurturing relationships with students and created a climate of respect among them. This was a crucial aspect recognized by researchers, teachers and teaching assistants.

> "All the activities planned were carried out, the students worked in an enthusiastic and respectful way with each other. The educators were enthusiastic, respected the children and they answered being kind with the educators and between them".
> "The boys and girls interact with each other without involving conflicts; they are willing to learn new games and make companions; the activities consisted of an approach to science without taking them so far away from their daily experiences."

Finally, another strength of the program implementation according to researchers and educators was that the teaching assistants were available for the students through the whole session each day. Their presence provided a sense continuity and facilitated group management, i.e., providing structure through daily routines, particular songs for the group, etc.

> "Having a teaching assistant during all the morning with the same group was a facilitator because the children knew the routines they have conducted on the first module. It fostered a sense of continuity and better articulation between the courses and modules".

5.2 Difficulties

The difficulties identified in this pilot version of the program refer to two different issues: infrastructure and materials, and teacher management of student emotions. Difficulties are seen in this work as restrictions or deficiencies that limited the implementation of the program generated from internal decisions, facts or issues. In this sense, difficulties might connect with opportunities of improvement, which are described from the participants' point of view in section 5.3

Regarding the weaknesses reported by teachers and teacher assistants, the most frequent comments represented the infrastructure and were related to the inappropriate design of the university furniture and classroom spaces to accommodate the needs of children. There was agreement on the traditional university classroom arrangement, usually with fixed seats, did not meet the needs for comfort, versatility for activities, and movement required in children's education. Similarly, on some occasions, the program's materials were not the most appropriate for the tasks, especially for artwork. Particular attention should be put on the textures and characteristics of the resources requested by the teachers to fulfill the objectives, because guided exploration and expression required some specific materialities which were nor replaceable.

> "We think it is really important to get the requirements that each course has in terms of materials and resources to teach the (STEAM) disciplines, especially regarding equipment of the classroom, i.e. tables that can be moved to reorganize the spaces, access to water for arts and science".
> "(Something to improve is) the classroom infrastructure; lack of tables and chairs adequate for children' age."

The second area of concern was related to teachers' management of student frustration. A few students, especially in the groups of 7-8 and 9-10-year-olds had difficulties working in teams; other students with high learning expectations occasionally were very self-critical and perfectionistic, which led to strong, usually disruptive reactions when they thought their products were not what they expected. Bearing in mind that most of the teachers did not have pedagogical formation, as researchers we believe some of the difficulties of students' behavior management could have been explained because of the lack of early childhood education preparation in teachers. However, the teachers attributed these difficulties to external factors, i.e.:

> "There were some problems to solve, both in terms of discipline and emotional regulation, but we need to take into consideration factors such as the hour of the course, the hot weather, and the tiredness of children."

As researchers we believe that keeping class time within the average attention span and closely monitoring of children's fatigue may help prevent episodes of disruptive behavior. It is important to note that part of the innovative structure that was piloted in this version was the inclusion of younger children, 3-4-year-olds. For some of them adjustment to staying in the classroom without their parents took a long time and some emotional dysregulation appeared during the first days. Considering that this was a one-week program, this situation might have affected their disposition to learn and make the best of this short-time program.

Finally, from the coordinating team's view, the program design needed more articulation between the courses and STEAM areas. They observed a difficulty regarding the integration of mathematics contents or skills into the activities. The connection between topics and skills between the courses might avoid redundancies and help with curricula alignment. This last element is discussed in the next section as an opportunity for the program improvement.

5.3 Opportunities

The opportunities for program improvement that were most frequently mentioned related to articulation between courses. During the final learning exhibition, teachers and researchers had a chance to learn in more detail what the other courses had done and accomplished, and many connections for future collaboration were identified. Although the teaching team for each age group met before the program started, sharing detailed lesson plans, and having other occasions to strengthen articulation between courses during implementation was suggested, they realized there were opportunities to improve the program with more time dedicated to aligning the activities. This element is relevant in the light of the integrated STEAM orientation of the program and introduces a priority for the future implementation rounds.

> "As teachers, we think that with better articulation and being more organized by discipline, we can potentiate our courses. If we look for more articulation, we need to be aware that it requires time, more work, and more prior team meetings".
> "It would have been an ideal scenario to get a prior articulation between both courses (of an age range)."

Moreover, some researchers and teachers proposed as an opportunity for the program to grow, testing how integrated science and arts can enrich children's educational experiences with atypical development (e.g., Asperger syndrome) or special learning needs, considering that there are academics in the university who work in special education and curricular adaptation for responsive education.

6 Discussion

The purpose of this study was to document the design and implementation of a university-based enrichment program in science education for young children. Two novel features of the program course design were the integrated STEAM approach and the infusion of a gendered approach to encourage visibility of participation of women in science. We included the "A" in STEM because of the natural link with early childhood and pre-school education. Our study found this element allowed implementing activities that engaged students grounded on children's natural interest in how the world works, which has also been stated by Monkeviciene et al. (2020). The teachers, all female, provided several opportunities to learn and express their advances with diverse materials and formats.

Arts played a crucial role not only as a way of communicating or expressing results of the learning processes, but also helping children to connect with the multiple forms and materialities for learning. We have described the list of courses, their objectives and the approach they had related to STEAM disciplines. In the program context the pilot version under evaluation included environments, settings and activities that encouraged children to explore natural objects and phenomena such as water, soil, heat, motion, plants, animals, the human body and systems such as the Ecosystem, the Earth, the Solar system. It also aimed at children exploring and creating models of these processes, phenomena and systems aided with technology and arts. Within the technology connections, the students were encouraged to use measuring tools, magnifying glasses and instruments such as microscopes, scales, seismograph, using augmented reality, among others.

By design, the intervention selected passionate young female scientists and artists to teach the integrated STEAM courses, all of which were framed historically to highlight the contribution of notable women in the areas. Therefore, the role of women in their respective disciplinary fields was experientially integrated into teachers' lesson plans, and through role-modeling teachers engaged students from different ages in authentic scientific practices. We consider this fact in our program to face the known discomfort feeling of early childhood educators when teaching science (Monkevincene et al., 2020) by including history of women in science and highlighting the role of arts in the construction of scientific practices. This perhaps helped the teachers to familiarize with the STEAM approach and overcome the unwillingness found by other authors (Nesmith & Cooper, 2019; Sharapan, 2012). Moreover, most of the teachers in this study embodied positive role models of women in STEAM areas, which was one of the program objectives. However, more research is needed to determine if the participants considered this a benefit or began to question or challenge the stereotype of male-dominated STEM areas. To this point, a limitation of this study was not measuring gender stereotypes at the beginning of the program, which would have been a valuable element for research and practice. Regarding the gender focus of the course presented in this version of the program, we cannot confirm if this may have had a role in the student learning experience. This element was not mentioned by researchers, educators or teaching assistants. Thus, the question of if short-time experiences such as *Pequeños Científicos* might trigger shifts in the way young girls perceive themselves (Olsson & Martiny, 2018) is still an open question.

Similarly, teachers' sense of competence in their topics was not an issue in this program as they were successful in integrating the STEAM areas and going beyond each discipline in order to create enriched learning opportunities for children. This finding reinforces the role of integrative pedagogy by placing the children at the center of the process of learning, rather than focusing the experience on the axis of the content. We agree with Sharapan (2012) that holistic experiences, connected with children's interests and natural environments have the possibility of being a transformative learning experience. We observed the holistic approach in the design of the courses, and all the participants reception of the activities and the subsequent evaluation of *Pequeños Científicos* program was good which implies it was a satisfactory experience for them.

Acknowledging that this might be an ideal scenario to engage children in science, it is important to recognize that self-selection might have contributed to current findings. Nonetheless, as researchers we do not consider this as a weakness. This type of project has value because it offers an educational opportunity to students that need it for their advance in knowledge and passion construction. Despite, we see this issue in the light of conducting to a question for future interventions, for instance, with pre-school teachers' challenges in scenarios where conditions for implementation might be very different. Some of the challenges or concerns reported by other studies in regular education (Çiftçi, Topçu & Foulk, 2020; Simoncini, & Lasen, 2018) were not found with participant teachers, perhaps because their characteristics. Thus, replication or transfer of this experience may be more likely within university contexts with similar highly qualified and committed academic teachers willing to adopt an integrated STEAM approach, with children who like to learn more about these areas.

A possibility for future research is to conduct longitudinal studies with comparison groups of students that participate in several versions of the program and other cohorts that have participated sporadically and not participated, in order to test diverse variables as outcomes of the program. This is particularly relevant in contexts of high educational inequality such as Latin America, however, it transcends the relevance to other contexts on which male-gender stereotypes are still dominant. In this work, we have shown the characteristics and the implementation evaluation of a program mainly delivered by women, with a gendered approach based on role-models and history of relevant women in the disciplines, which is an original emphasis that might illuminate the possibilities for the STEAM educational community beyond the specific program described here. We consider that history of woman in STEAM areas is a potent alternative to work in gender-empowering objectives, even in contexts with economic deficit, places with a lack of resources or where materials are not available.

Overall, the program engaged participant students positively in their STEAM learning processes, and they demonstrated enthusiasm during the process and the learning products exhibited at the end of it. The high levels of children's engagement and cooperation found by this study are a strength of the program and concur with the findings of Aronin & Floyd (2013), who also observed that STEAM experiences promoted student interest in learning. The aspects that McClure (2017) found crucial to increasing student engagement - children's natural curiosity, family educational encouragement and enjoyable science, also played an important role in the implementation of the *Pequeños Científicos* program. However, it is important to note that besides parents' encouragement of their children to join the program and participate in the learning exhibition at the end of the program, given the brief duration of the program, there were no other instances of direct collaboration with parents. This might be an aspect to reinforce in order to sustain program effects over time. In spite of being a self-selected group, many of the children in the sample were not exposed to these experiences at home, as reflected by their response to the survey (e.g., disagreement with "I like talking about science with my family"). We consider that family attitudes and experiences with science are important issues when designing interventions for general school populations.

Regarding the impact measurements of the program, we believe that the student selected instrument was not sensitive enough to capture changes, or, the intervention was too brief to produce changes. Still, we as researchers cannot estimate how educationally relevant this difference, if it existed, would be. The students who participated in the program had already expressed their high interest in the STEAM areas; therefore, measuring possible improvements in their STEAM attitudes or interests is difficult. A recommendation for future developments is to design instruments oriented to integrated STEAM in early childhood education, which might explore the attitudinal dimensions or the diverse sources of children's learning support such as parents, friends, and teachers.

The measurement interval might be another issue, also considering that students' self-selection variables might have influence their attitudes already positive towards sciences. Although the length of the program was not identified by the participants as a problem, we wonder if a week to tight to accomplish all the program goals. In fact, it is still a challenge to identify sensitive measures that might capture small changes or emergence within the short time span of the program. These elements are essential to improving the design and implementation of educational innovation to promote STEAM learning beyond the regular classroom.

Given differences in the age range of participant children, course design needs to consider different time allocation and formats for younger students in order to accommodate their attention span, working memory, and time to warm-up with the requirements of the learning situations. Most of the teachers in this program did not have prior pedagogical training, and the difficulties of behavior management in the classroom could potentially have been alleviated with support from teaching assistants experienced with young children. Nonetheless, it is interesting to note that teachers did not link their lack of capacitation in early childhood education with this difficulty, which might mean a blind spot. We believe that stronger preparation of the support staff would be useful to encourage more confident action and closer connection with the students, helping to overcome emotionally difficult situations.

In terms of transferability, we encourage the potential of generalising the alliance between the university context and early childhood education in STEAM areas to the diverse educational contexts on institutions as a model. Considering that education in the early years is an excellent space for promoting integrated learning (DeJarnette, 2018; Çiftçi, Topçu & Foulk, 2020), approaching the interest of university academics to work with children is a possibility that other institutions -i.e. scientific academies, colleges, research centers- might take into consideration as a link with society and communities particularly affected by inequalities. However, it is important to count with the appropriate infrastructure and identify safe spaces that best suit the needs of children. We strongly believe that learning outdoors or in spaces capable of accommodating for instance, mats rather than traditional furniture, might help to overcome this problem. Another suggestion from the experience gained in *Pequeños Científicos* is to consider student concentration time and divide the university schedule into shorter periods, combining it with breaks for free play in order to be responsive to the needs of young learners.

Finally, we want to problematize and demystify stereotypes about the capabilities of young children in STEAM learning, highlighting the notion that enriched opportunities for learning are not only valuable for children's education but trigger their development in several dimensions. Interestingly, participants were surprised to learn forms of connections between science, mathematics and arts, which might enhance identity development, especially in the academic self-concept (Dou et al., 2019). We consider that strengthening the links between sciences, interactive technology such as new advances in labs (Proudfoot & Kebritchi, 2017) with the arts and mathematics is crucial to construct knowledge with children from the early years. It might lead to understanding sciences, technology and mathematics as creative endeavors and, consequently, making it easier and more significant to include the STEAM approach in this age range (Sharapan, 2012). In the *Pequeños Científicos* program integrating artwork provided crucial opportunities for students with diverse interests to explore and communicate how they carried out their learning processes as well as the difficulties they identified using different materials. Thus, the creation process was not only expressed but afforded by the artwork, which makes STEAM approach including arts a valuable advance from STEM models that in our view, perhaps helps young learners and teachers with no prior training to make the best of the integrated disciplines without reluctance.

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Appendix

Students' survey (in Spanish)

SURVEY	do I accept this information is used for research purposes? YES-NO	
Name:	Age:	Date:

Please mark, Paint or circle the face that represent your option in front of each sentence. Remember that there are not correct or wrong answers, please answer honestly.

Sentence	**Agree**	**Neither agree nor disagree**	**Disagree**
1. I think that science is interesting			
2. I like to learn about science and technology			
3. I like listening to my teacher when she speaks about science			
4. Science and technology are good for life			
5. Science and technology are useful and can help us			
6. I like talking about science with my family			
7. Understanding science is important			
8. All the students should learn these topics			

Thanks!

PENTA UC Observation protocol

LESSON OBSERVATION GRID

1. **Protocol objective:** To monitor the teachers' work during a course, take field notes of activities that promote integrated learning, to give feedback to teachers based on the evidence collected.

2. **Lesson identification**

Teachers' name		**Observers' name**	
Course		**Number of students**	
Course objectives			
Lesson objectives			
Date		**Time of observation**	

3. **REGISTER**

During the lesson, observe and register elements related to each dimension and teachers' actions as "evidence."

DIMENSION	INDICATORS	YES	NO	EVIDENCE
Lesson structure	1. The lesson objective is presented			
	2. Prior knowledge is activated			
	3. There are activities or procedures oriented to reach the lesson objective			
	4. The activities are formalized or synthesized during the lesson, checking the fulfillment of the lesson objective			
Methodologies	1. The methodology is oriented towards students' meaningful learning			
	2. The methodology is oriented towards reaching the lessons' objectives			
	3. The methodology is adequate to the course discipline(s)			
	4. The methodology promotes the development of critical disciplinary skills or transversal skills			
	5. The methodology promotes the discipline(s) attitudes			
	6. The teacher uses precise vocabulary according to the knowledge area(s)			

	7. The teacher integrates into the lesson the students' interests, problems, and themes they want to solve or develop			
	8. The methodology develops students' higher-order skills			
Classroom interaction	1. The teacher promotes students' participation in the lesson			
	2. The teacher promotes student-student interaction			
	3. The teacher validates individual and group students' interventions			
	4. The teacher promotes the participation of students' less interactive			
	5. The teacher promotes students' regulation and self-regulation			
Classroom climate	1. The teacher favors the respect of diversity and dignity			
	2. The teacher integrates errors as part of the learning process			
	3. The teacher promotes formatively conflict resolution in the classroom			
	4. The teacher promotes the agreement and respect of norms and the consequences of transgressions			
	5. The teacher promotes respecting the turns to speak			
	6. The teacher promotes an environment of confidence to express opinions and questions			

4. OTHER FIELD NOTES

Please complete with the observation elements not included on the grid or those that combine the prior dimensions.

Dimension(s)	Qualitative register	Assessment	Suggestions

Promoting student interest in science: The impact of a science theatre project

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Researchers have often noted the potential of the performing arts to support STEM education – especially in heterogeneous classrooms. This article reports on the implementation of a science theatre project in a secondary school class located in a disadvantaged area of Hamburg (Germany). In the accompanying research study, effects on students' interest in STEM and artistic expression were surveyed. Data analysis using *t*-tests shows that the artistic work significantly increased students' interest in physics and chemistry, and specifically in the process of galvanization, the project's focus topic. The analysis also revealed a growth in students' knowledge of cultural practices, self-confidence, joy in individual artistic expression, and classroom spirit during the course of the project.

Keywords: STEAM education, science theatre, art-informed education, out-of-school learning, cultural education

ARTICLE DETAILS

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1 Introduction

In today's schools, globalization is progressively increasing diversity as students from a broad spectrum of social, ethnical, and personal backgrounds bring a wide range of cultural habits and practices, expectations and beliefs, interests and languages to the classroom. Yet standard classroom teaching in Western industrialized societies supports and reproduces a unitary and linear concept of science, one that is communicated and supported via teacher-centered and recipe-like instructional techniques. This way, "conceptual practices of culturally others" (van Eijck & Roth, 2011) are excluded from Western science and science education. At the same time, solid science and technology skills are needed if students are to become informed and responsible members of our knowledge and information society (Kolstø, 2001). One potentially very effective way to promote culturally diverse and inclusive science and technology education is to connect it to creativity and the arts (Reif & Grant, 2010; Madirosian, 2003). In this article, I describe and analyze how a performing-arts informed teaching project about galvanization affected classroom learning with 13- to 16-year-old girls and boys at a German district school. The study focuses on the question, if the science theatre project helped to increase students' interest in physics, chemistry, galvanization, and artistic practice.

2 From STEM to STEAM

About fifty years ago, at the opening of the San Francisco Science Centre, its founder Frank Oppenheimer stated that science, art, and human perception are entwined (1972). In this vein, physicist Kent Eschenberg (2006) notes that outstanding research in the fields of natural sciences is related to the "ability to imagine new realities" and to abilities that "are traditionally thought to be non-scientific skills". And Guy Boy, a physicist at Kennedy Space Center, discusses the need to integrate the arts into STEM (science, technology, engineering, and mathematics), creating STEAM, to account for the complexity of phenomena, knowledge, and knowledge creation. He points out that, particularly in education, transdisciplinary connections between STEAM areas are required to account for the intricate lifeworlds of young people (Boy, 2013). During the past decades, the notion for STEAM has increased (Perignat & Katz-Buonincontro, 2019). The "Arts at CERN" project is another strong indicator that STEAM is no longer a marginal perspective:

> [Arts at CERN seeks to] pioneer new ways of bringing together artists and scientists [to] lead the conversation about art and science [...]. Positioning artists and scientists together within the larger scientific context, our programmes foster new approaches to research, experimentation, and artistic production. Furthermore, we want to question how art and culture can form novel visions of a highly specialized environment and what common grounds can be shared between art and science. (CERN, 2020)

2.1 STEAM in education

While STEM researchers are more and more informed or sensitized about STEAM, predominant paradigms and practices of teaching STEM in schools present the disciplines as static, coherent, and linear, projecting it as a self-sustaining, self-reproducing cognitive process (Schulze Heuling, 2017). STEAM can provide a responsive pathway for education towards 'whole STEM learning' (Allchin & Zemplen, 2020) in which students experience themselves as 'science makers,' thus enabling them to engage with the complexity of STEM undertakings instead of discouraging potentially interested teenagers from developing an interest in STEM. Furthermore, with teaching towards STEAM rather than STEM, educators can provide an education to their students that fosters diverse and culturally responsive classrooms by enabling the co-creation of contextual knowledge such as aesthetical, emotional, biographical, embodied and practical knowledge in relation to STEM (Gedžune & Gedžune, 2011; Reif & Grant, 2010). Typical ways towards integrating the arts in STEM education are art-informed and art-based approaches (Khine & Areepattamannil, 2019; Marshall, 2014): Art-informed teaching refers to approaches which can be characterized as using the arts and art-related creative processes and products as vehicles for conventional subject education. In contrast, art-based education in STEM, which can also be referred to as STEAM education, aims to teach towards STEAM, acknowledging the arts and artistic processes as an epistemic praxis of equal value.

A growing body of research into art-informed and STEAM education confirm positive educational effects. Art-based or art-informed learning and instruction in STEM-subjects enhances students' intrinsic motivation (Reimer, 1970; Fiske, 1999; Eisner, 2002; Irving, 2015), lesson commitment (Stronge, 2002), social learning (Mardirosian & Fox, 2003) and cognitive development (Schellenberg, 2003; Miendlarzewska & Trost, 2013). Other studies found that students react to art-based education with increased learning commitment (Ritter, 1999), stamina (Stronge, 2002), and an increased willingness to take risks with respect to knowledge discovery (Jensen, 2001). Positive effects were found for higher-order thinking (Burton, Horowitz, & Abeles, 1999), critical thinking and reflection (Snyder, 2017), conceptual thinking (Efland, 2002), as well as interdisciplinary and interlaced thinking (Psilos, 2002). Furthermore, art-based instruction is found to be a mediator variable for learning, one that shows a positive influence on students' ability to learn independently (Fiske, 1999). Several studies provide evidence that dance and performance art support students' inquiry learning and communication skills in verbal and non-verbal ways and foster an integrated learning process in STEM-subjects (Burg & Lüttringhaus, 2005; Le Maréchal, Bertin, & Hallet-Eghayan, 2009; Gollin, 2016; Najami, Hugerat, Kjalil, & Hofstein, 2019).

Furthermore, art-based and art-informed education increases teachers' (Oreck, 2014; Garvis & Pendergast, 2010) and especially STEM teachers' (Macintyre, Buck, & Beckenbauer, 2007; Tracey, 2009) self-efficacy. Particularly prospective STEM teachers benefit from integrating the arts in non-arts subjects because it fosters the interconnection of knowledge gained from different subject areas (Amabile, 1983; Weisberg, 1999; Veen, 2015; Irving, 2015). Evaluation of the North Carolina school program "the arts and education reform" showed that art-based techniques provide teachers effective tools that help them to teach adaptively and support students individually (North Carolina A+, 2020). Burton, Horowitz, and Abeles support these findings and show that art-based teacher trainings increase instructors' willingness to participate in further trainings (Burton et al., 1999).

Predominant art forms in conjunction with science and mathematics education are the performing arts (Heering & Schulze Heuling, 2020; Williams, 2011; Stolberg, 2006). As Stolberg suggests in his review, one reason the performing arts in science and mathematics education are preferred over other art forms is that they adaptively allow for collective work in larger groups. However, all art forms allow the artistic modelling or inquiry processes taking place in the classroom to be dynamic and performative.

This might be one reason why it is now becoming increasingly common also for university lecturers to teach STEM alongside performing arts. Lucy Irving and Carl Senior, for example, have developed an entire YouTube tutorial in which they present choreographies to explain basic statistics (Irving, 2015). Others go beyond the representational state of artistic expression entwining aesthetical, emotional, embodied and practical knowledge. For example, Schultz and Brackbill (2009) successfully improved medical students' abilities to interpret electrocardiograms by infusing their lessons with rhythmic dance movements. Karen William's (2011) introductory courses to lab techniques in the science laboratory are informed by choreography and motion analysis. Characteristic for her approach is the understanding of the hidden, non-verbalized somatic knowledge of lab routines as choreographies themselves. Finally, some studies show that the arts are furthermore extremely promising for student assessment (Katz, 2016; Veen, 2012; Knowles & Cole, 2008; Macintyre et al., 2007; Soep, 2005).

3 Models and approaches for integrating the arts in STEM education

There are several models for integrating the arts in (non-arts) education (Fogg & Smith, 2001; Annenberg, 2003; Leavy, 2015) of which two should be introduced here. The model developed by the Lincoln Center is called "Aesthetic Education, Inquiry, and the Imagination" (Greene, 2001; Holzer, 2005). One major characteristic of the model is that it has been derived from educational practices that focus on aesthetic learning. Its core qualities are comprehended in nine "capacities": noticing deeply, embodying, questioning, identifying patterns, making connections, exhibiting empathy, living with ambiguity, creating meaning, taking action, reflecting and assessing. Physicists have identified five of these capacities (noticing deeply, embodying, questioning, identifying patterns, and making connections) as directly relevant to their research and educational practice (Weisskopf, 1976; Veen, 2012; Boy, 2013). The Lincoln Center is currently developing "curricular frameworks in aesthetic education" based on the nine capacities. The other model I would like to mention is the "artful learning" model of the Bernstein Center and is offered as advanced training that targets active teachers. This model groups teaching strategies, learning techniques, and suggestions for educational practice around a four-level, process-oriented model—the Bernstein process of "experience, inquiry, creativity, and reflection" (Bernstein, 2003).

4 Science Theatre

Deliberately integrating the arts and aesthetic perception into education promotes awareness that science is culturally dependent and a conceptual and social practice. This, in turn, can help students embrace science and science-related topics as something related to their own experience. Characteristic for the intersection of science and art is the willingness to engage in a learning journey and commit to experiences that can change the way we think by means of deep observations in the world, systematic connections, interpretations, sharing and thinking. Science theatre is an amalgam, a "patchwork genre," that combines artistic research, dramaturgical and science epistemology, and content from artistic and science domains (Chemi, 2017).

As a practice, it makes use of (post-) dramatic approaches, drama pedagogical tools, and various forms of media to create and disseminate knowledge. In this sense, it is much more than merely staging a play that somehow relates to science; rather, it is a process that involves scientific and artistic practices that might or might not lead to a public demonstration. Science Theatre is a process that involves perspectives from both, art and science, and engages them in a trans-disciplinary exchange. Science theatre performances are expressions of such dialogues, of a trans-disciplinary discourse in which students explore and negotiate issues related to both domains, learning about epistemologies, content matter, dramaturgical techniques, history, and philosophy as well as social, emotional, and moral aspects (Orthofer, 2013).

5 The project

The project was initiated by the science teacher of the participating class. During a teacher training led by the German "Kulturagenten" (cultural agents) programme, an initiative set up to foster cultural education in schools, the teacher stated a strong need for alternative educational approaches towards science in order to reach the many at-risk students in his classes. Upon this statement, a representative of the Kulturagenten programme intensified the contact with the teacher and the school, which lies in a social focal point of Hamburg. A meeting with potential project partners was set up and finally, the Kulturagenten programme decided to fund the entire project.

The content focus of the project was on the phenomenon of galvanization and the related science disciplines physics and chemistry. Galvanization is based on the principle of electrolysis. Nowadays, galvanization is used as a technical term describing processes of surface refinement. Typically, a thin layer of a conductive metal is applied to a workpiece to protect it against corrosion. Because some of the coatings look very shiny compared to the workpiece material, it can be easily associated with something that is glamorous on the outside but might not be so glamorous on the inside. Therefore, the students gave the project the name "Not All That Glitters is Gold."

5.1 Project preparation and overall structure

The project was led by two artists, one artist-scientist, and the two classroom teachers of which one was the initiating science teacher. All five were involved for the duration of the project, which extended over three months. The project design was primarily determined by structural conditions of the school and pedagogical desiderata.

It furthermore aimed to provide students with artistic, cultural, and subject learning experiences and, at the pedagogical level, to give them an artistic and cultural learning process that sprang from the combined, cooperative efforts of artists, scientist and teachers. Another aim was to unite an art-based learning process with STEM-subject learning. In the project, the students negotiated scientific knowledge creation and representation as well as industrial labour and workshops in artistic ways and during classroom sessions. Moreover, it was a curricular demand that the project also addressed issues of early-career guidance which it did on behalf of the job profile of a galvanizer.

At a first meeting, the overall time-structure of the project (see Figure 1) and the conditions of the school and the availability of the theatre space for rehearsals and working schedules were negotiated. It was set that the project should begin with a kick-off workshop (Phase 1), followed by a visit to a galvanization factory (Phase 2), a performance-art workshop (Phase 3) and an intense working week in the theatre (Phase 4) where, at the end of the week, the performance would be staged publicly. Between the kick-off workshop and the performance-art workshop, the students worked with their teachers on the theoretical fundamentals of galvanization and around the visit to the galvanization workshop (preparation for visit and reflection).

On a subsequent meeting among the three external experts, all agreed on an overall artistic-pedagogical approach and sketched the content for each of the project phases. For example, during the kick-off workshop, as a means of introducing students to scenic work with movement and speech and to STEAM, students should be made familiar with the principles of "Show and Tell" (Jackson, 2005). Show and tell combines elements of lecture and theatre, bringing together the acts of saying and showing in the context of a scenic set. Show and tell allows the participant to experience and reflect on the performative dimensions of scientific knowledge production. The aim was to increase students' sensation that STEAM offers them a pathway to experience themselves as science and technology learners or even as science and technology makers.

Further objectives of the kick-off workshop were to encourage students to apply artistic freedom and to freely associate their own impressions and ideas to scientific content and to build up their anticipation for the project. Because public presentations were scheduled to take place right at the end of the intense working week (Phase 4), it was also important to collect artistic material during Phases 1-3, such that the final intense working week could build on the three prior phases. For this reason, already during the kick-off workshop, the class was divided into smaller groups. Each of the three groups found a thematic focus which they would further explore during the course. The three groups worked on (1) working life and professions, (2) transforming phenomena of galvanization into motion, and (3) shiny but fake.

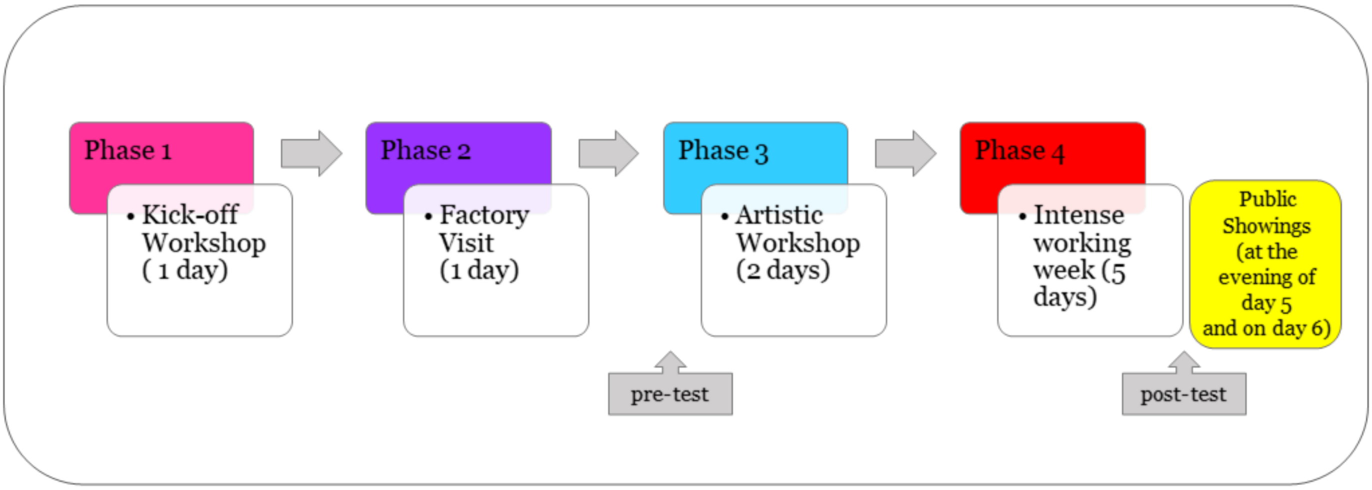

Figure 1. Timeline of the project.

5.2 From kick-off to performing in public

Since doing and experiencing factory work and science were important issues within the scope of this project, we wanted the students and ourselves to experience in real life what happens in a galvanization factory. To this end, after the kick-off and before the two-day artistic workshop, all project participants attended a factory tour to the Böge factory in Hamburg-Bergedorf. During the tour, students technically and sensually experienced the process of galvanization. They heard the sound of clinging metal, smelled the acidic air, and saw the physical labour of the metalworkers. The students also talked to the company owner and asked a lot of questions. Subject knowledge on galvanization was prepared in school.

One week after the field trip, the students, the three external experts, and the teachers met for the workshop on theatre practice, which took place in the Forschungstheater in Hamburg (research theatre). After a warmup, the students intensified their work with show and tell, followed by a break and then a lecture performance on galvanization given by the artists. The lecture performance was designed highly interactive. Charge transport through ionization and electrolysis, as well as sensory and social aspects of working in a galvanization factory were performed. In this way, the students were further familiarized with what it can look like to approach a techno-scientific subject from a STEAM perspective.

Finally, the students were asked to write down their ideas, wishes or unanswered questions. This list contained important information for us, the external experts, and was used as a starting point to design the intense working week (Phase 4). Analysis of the list revealed that the launch had inspired and motivated the young people, who offered suggestions regarding which artistic and thematic issues they would like to intensify during the project week. During the interval between this workshop and the project week itself, which would take place a couple of weeks later, students attended regular school lessons.

Phase 3 of the project, the main project week, began with an extensive warmup and performance-pedagogical ensemble work. The smaller groups worked progressively on their scenes, which were given the working titles' Transport,' 'Gangster,' and 'Fashion Show' (see Info Box). In addition, the entire class had developed the idea to negotiate their impressions of the factory visit and what they had learned about the profession of a galvanizer in the form of fictional interviews with the company leader. These interviews were partially based on students' notes made during and after the tour.

INFO BOX

'Transportation'-scene

Three bank robbers steal the gold reserve of a large bank. After a turbulent journey they successfully deliver the stolen gold to their gold-addicted boss in his all-gold headquarters. Because the boss himself is the only non-gold-plated object in the office, the gangsters decide to galvanizing him with the stolen gold.

'Gangster'-scene

Starting point of this scene was to think galvanisation the other way round. The idea is to coat a surface not to make it look shiny and precious but to make it look ordinary. In this scene the treasure of a museum robbery was delivered to a galvaniser who is asked to cover the treasure with chocolate for camouflage. Of course, this camouflage bares some surprising trouble…

'Fashion-Show'-scene

A galvanising process usually is used to refine surfaces. This scene is composed of students' associations that were born out of critical reflections with the word 'surface'. In a world of glamour and glitter a young woman refuses to wear make-up, high heels, and extra-large earrings. What are the consequences for her – and for the beauties on the catwalk?

Since the physical phenomena of a galvanizing process should also be part of an artistic and creative learning process, the whole class developed short scenes representing what they had learned about the physical and chemical fundamentals. The first scene was a choreographic miniature inspired by classical visual models of atoms and molecules. The second choreographic miniature was a danced model of the formation of molecular bonds. The third choreographic scene was based on charge transport model of electrons and ions. The science teacher of the class used the artistic process and artistic miniatures for his classroom sessions at school to reflect on aspects and limitations of scientific models.

At the end of the project week a collective performative collage out of the different artistic material was created. There was also the possibility – particularly for those students who were interested – to participate in light and stage design and other stage management duties.

6 Accompanying survey

Engagement with students, work on the project, and a tight timeline meant that the pedagogues had very limited time for an in-depth project evaluation. The pragmatic choice was to monitor selected aims of the project in an accompanying pre-post questionnaire survey. The focus of this study was to find evidence if the project had an impact on students' attitudes towards the subjects of physics, chemistry, galvanization, and their appreciation of artistic practices.

6.1 Methods and sample

All participating students were in the eighth grade and in the same class at the lower secondary level of a German Stadtteilschule (district school). The sample was not randomized and there was no control group. All data were assessed with a questionnaire (pen and paper). There were 25 participants in each, the pre- and post-test sample. The first measurement was taken at the beginning of the first meeting in the theatre (Phase 3). Post measurement was six weeks later, at the end of Phase 4, before staging the performance to the public. All questions were to be answered on a seven-point Likert scale (1 = "not agree" to 7 = "fully agree").

Since this study makes the claim that combining performing arts with STEM education is particularly suitable for working with heterogeneous classrooms, the demographic and social composition as well as the distribution of personality traits of the present sample were surveyed. Let us first look into demographic and social characteristics: Students' intercultural background was assessed asking if another language besides German was spoken at home. This was positive for 92 % of the students. A variety of free time and cultural activities was also assessed, showing that more than half of the class engages in group sports and almost a third of the class plays a music instrument. To be precise: About 23 % of the students reported engaging in individual sports, 58 % in team sports, and 19 % said they do no sports in their free time. In our sample, already 39 % of the students had attended a dance project, and about two-thirds had participated in previous theatre projects. Furthermore, nearly 27 % of the students reported that they played a musical instrument. Students' personality traits were assessed in the pre-test, using an age-sensitive reformulation of the Big-Five-Inventory-10 (Rammstedt, Kemper, Klein, Beierlein, & Kovaleva, 2012). In a nutshell, students ranked themselves in the middle of the Likert spectrum, with only small standard deviations (details are provided in Table 1). Notable spikes were found in the dimensions "extraversion," "openness to experience," and "agreeableness." "Extraversion" (M = 4.40) and "openness to experience" (M = 4.44) scored slightly higher than the other dimensions. Furthermore "extraversion" has a very small standard deviation (SD = 0.82). The lowest score yielded the dimension "agreeableness" (M = 3.86). All in all, from the data assessed we propose that the majority of the students could be described as having a multi-ethnical background and being culturally active, extraverted, and open to new experiences.

Table 1. Results for the Big-Five-Inventory (1 = "not agree" to 7 = "agree")

Subject	Sample size	Mean (*M*)	Standard deviation (*SD*)
Extraversion	25	4.40	0.82
Neuroticism	24	4.19	0.92
Openness to experience	24	4.44	1.05
Conscientiousness	24	4.21	1.05
Agreeableness	25	3.86	0.99

To assess the students' interest in the project related STEM-subjects, appreciation of galvanization, physics and chemistry was measured with five items for each dimension (see Table 2). While all the parameters of Cronbach's α were above .8, the small sample size of n= 50 must be considered. In the second part of the questionnaire, students' perspectives on different aspects of the project, such as artistic practices, self-perception, and classroom climate were assessed.

Since the data is a paired sample with a very small sample size, dependent t-tests for paired samples were used in the analysis, calculating Wilcoxon signed-rank tests for cross-checking every dimension. Finally, Cohen's d is provided to estimate the effect size (Bortz, 2005, p. 145).

Table 2. Quality of measurement for STEAM aspiration.

Dimension	n of Items	Cronbach's α	Item example
Galvanization	4	0.89	I want to know more about galvanization.
Physics	5	0.82	I am also interested in physics outside school.
Chemistry	5	0.82	Chemistry gives me fun.

7 Results

Analysis of the participants' interest in chemistry, physics, and galvanization shows an increase for all three dimensions. As Table 3 and Figure 2 show, significant changes in interest were measured for both the project topic (galvanization) and physics. The project had a remarkable effect on students' interest for the topic of galvanization, with an effect size of $d = 1.15$. Here, the mean changed from 1.67 to 2.54. The effect on students' interest in physics was also strong, with $d = 0.82$. The score increased by 0.41 scale points from measurement 1 to 2. It is worth noting that also the standard deviation is very small. This suggests that the entire group clearly experienced a positive change of attitude with respect to physics. No significant effect was found for chemistry between time point 1 and time point 2, but measurements for chemistry aspiration show very small standard deviations at both time points.

Table 3. Effects on aspiration of STEM-subjects (n = 24; scale: 1 = “not agree” to 7 = “agree”)

Dimension	t_1 ***M (SD)***	t_2 ***M (SD)***	**paired *t*-test**			**Wilcoxon Test**		***d***
			df	*t*	*p*	*z*	*p*	
Galvanisation	1.67 (1.00)	2.54 (1.22)	23	−4.00	0.001	-3.68	<.001	1.15
Physics	2.71 (0.68)	3.12 (0.84)	23	−2.83	0.009	-2.62	0.009	0.82
Chemistry	2.70 (0.88)	2.84 (0.90)	23	−0.97	0.341	-1.25	0.211	0.28

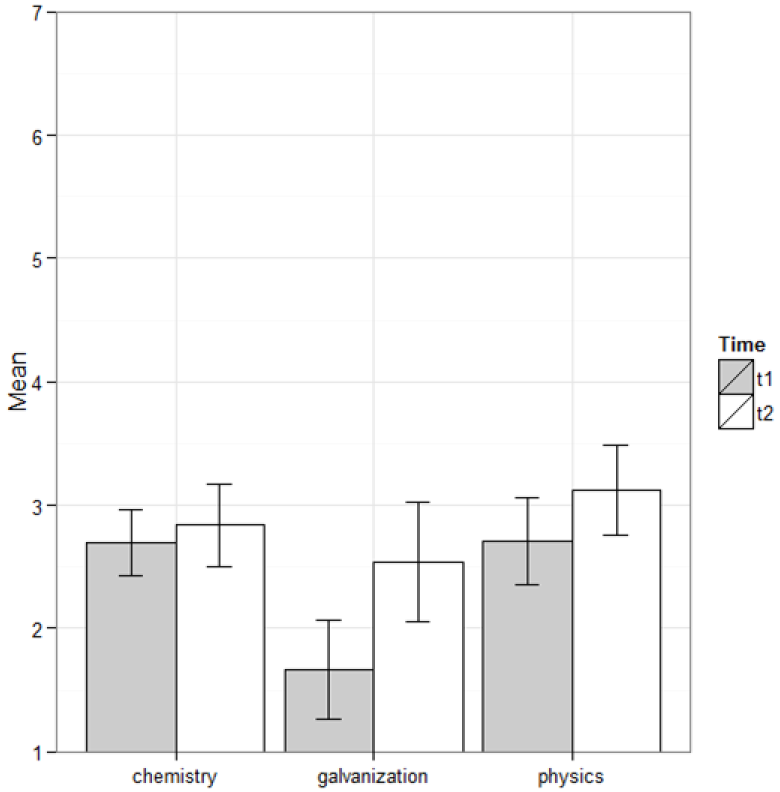

Figure 2. Change of appreciation for chemistry, galvanization and physics from time point 1 (t1, beginning of Phase 3) to time point 2 (t2, end of Phase 4). Scale: 1 = "not agree" to 7= "agree", Confidence level: 95%.

Let us have a look at the questions that tell us more about how students see the project, as well as how they experience themselves in the project, their creativity, and the learning atmosphere. The greatest effect can be noted for the statement "I can orient myself successfully towards the tasks of the three artists" with d = 1.08 and an increased mean ($M1$ = 4.38 to $M2$ = 5.46). We interpret this effect as indicating an increase in mastery experience or positive effects of verbal persuasion. It also suggests that the students gradually adapted to the artists' individual styles of teaching.

The statement "The whole class works well together during the project" was also ranked higher from time point 1 to time point to 2, with an effect size of d = 1.04. This result suggests that the pedagogical effect of art-based education was successful in creating an experience that fosters empathy and shared experience and social inclusion among the group of student participants. Although no significant effect was found for the item "I am more encouraged to try something new in the project than in school," the mean for empathy, shared experience and social inclusion increased from 4.33 to 5.08 scale points.

Table 4. Questions to get an insight into students' appreciation of the artistic process, aesthetic perception and self-perception (n = 24; scale: 1 = "not agree" to 7 = "agree")

Item	t_1	t_2	**paired t-test**			**Wilcoxon Test**		***d***
	M (SD)	***M (SD)***	*df*	*t*	*p*	*z*	*p*	
I have a good feeling for rhythm.	4.21 (1.45)	4.50 (1.25)	23	-1.77	0.090	-1.70	0.090	0.51
I have great interest to participate in an arts-project on galvanisation.	1.92 (1.38)	2.67 (1.31)	23	-2.07	0.050	-2.53	0.012	0.60
I have own artistic ideas I wish to realise in the project.	2.92 (1.53)	3.29 (1.27)	23	-1.00	0.328	-0.88	0.379	0.28
The whole class works well together during the project.	4.36 (1.25)	5.25 (1.39)	23	-3.19	0.004	-2.81	0.005	1.04
Creative work gives me fun.	4.00 (1.89)	4.25 (1.51)	23	-0.58	0.567	-0.57	0.567	0.17
I enjoy participating in creative projects in school.	4.08 (1.72)	4.63 (1.21)	23	-2.12	0.045	-2.07	0.039	0.62
I can orient myself successfully towards the tasks of the three artists.	4.38 (1.50)	5.46 (1.25)	23	-3.76	0.001	-3.18	0.001	1.08
I can express myself well using artistic means.	3.38 (1.53)	4.13 (1.04)	23	-2.48	0.021	-2.38	0.017	0.71
I have a precise understanding of what an arts performance is.	3.63 (1.61)	4.33 (1.40)	23	-2.10	0.047	-2.17	0.030	0.60
I am more encouraged to try something new in the project than in school.	4.33 (1.61)	5.08 (1.18)	23	-2.19	0.039	-1.53	0.126	0.63

Artistic and creative expression also yielded significant effects. In particular, the statement "I can express myself well using artistic means" scored significantly higher in the post-test with an effect of $d = 0.71$. This experience was reflected in the relatively high scores for the statements "I have great interest to participate in an arts-project on galvanization" ($d = 0.6$) and "I enjoy participating in creative projects in school" ($d = 0.62$). The score for "I have a precise understanding of what an arts performance is" ($d = 0.6$) also changed, indicating an appreciable increase in the participants' level of cultural education and awareness.

8 Summary and Conclusions

Adding to the growing body of research into STEAM and art-informed education in STEM, this report showed the positive impacts of a science theatre project on student interest in physics, chemistry, galvanization, and artistic practices.

The science theatre project "Not All That Glitters Is Gold" was a singular project with a lower-secondary school class, aiming to further education and to support the lived cultural diversity in a heterogeneous classroom. It also offered students an occupational orientation in the subject of galvanization. Engaged in art-based learning the participating students appeared to enjoy themselves with their classmates during the project; their interest in creative expression and hunger for knowledge in the related STEM topics increased. This impression was confirmed by the accompanying pen-and-paper survey, in which participating students reported having strong positive experiences. The data suggests that the students experienced themselves as proactive participants in the learning experience—that is, as more than mere receivers of content knowledge. The study results are in accord with those of previous studies outlined at the beginning of this article.

In retrospective, using the Lincoln Center framework (see section 3), for reflection, "Not All That Glitters Is Gold" provided learning within four of the nine core capacities, namely embodying, making connections, creating meaning, and taking action. The overall project and workshop design matched the Bernstein process (see section 3) of experience, inquiry, creativity, and reflection only to some extent. While artistic and subject-related experience was provided and creativity given its place to a large extend, inquiry and reflection remained less represented and accounted for in the project. There are most likely multiple reasons for this. In particular, this science theatre project took place within the confinements of an educational institution, thus having to act within the accepted boundaries of school education. Despite the wish to provide the students with a journey into transdisciplinary STEAM education, it soon became clear that, within the given conditions, the practical scheme had to be set up as an art-informed science theatre project. This way the project was adaptive to formal education to the extend as the existing values and norms of formal education were slightly questioned but not pushed forward or changed (Sterling, 2001; Schulze Heuling & Fooladi, forthcoming). In other words, within this educational project an equality between students' scientific and artistic inquiry into galvanization and the science related to it was not attained.

Additionally, a few methodological remarks should be made. First, the study is a case study with a small sample size and lacks a control group which both limit the empirical significance of the results. Second, a follow-up study would have provided information on the long-term nature of the measured effects. Third, it is noteworthy that specific student characteristics might have supported the positive study results: More than a third of the students had previously participated in a 'dance in school' project, nearly a third indicated to play a music instrument, which we interpret as having a background in cultural education, and finally the big-five analysis revealed that the class had the tendency to be extrovert and open to new experiences.

All in all, this study showed the positive impact of a science theatre project on students' interest in STEM. The significant increase of appreciation of the subject matter and artistic practices as well as improved classroom spirit show the strengths of simultaneously teaching art & science. Even more: Considering the intercultural background of the students and that both, school and environment of the students are located in a disadvantaged area of Hamburg, the study results clearly make a case for art-informed STEM education as a socially inclusive practice and for successfully promoting interest in STEM and the arts among disadvantaged students.

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