ORIGINAL RESEARCH
published: 03 August 2022
doi: 10.3389/feduc.2022.757866

Integrating Data Science and the Internet of Things Into Science, Technology, Engineering, Arts, and Mathematics Education Through the Use of New and Emerging Technologies

Maeve Liston[1], Anne M. Morrin[1], Trevor Furlong[2] and Leona Griffin[3]*

[1] Mary Immaculate College, Limerick, Ireland, [2] Independent Researcher, Dublin, Ireland, [3] Department of Education and Skills, Dublin, Ireland

OPEN ACCESS

Edited by:
Maria Meletiou-Mavrotheris, European University Cyprus, Cyprus

Reviewed by:
Ana Serradó Bayés, Colegio La Salle-Buen Consejo, Spain
Kelly Guyotte, University of Alabama, United States
Mairéad Hurley, Trinity College Dublin, Ireland

***Correspondence:**
Maeve Liston
maeve.liston@mic.ul.ie

Specialty section:
This article was submitted to Digital Learning Innovations, a section of the journal Frontiers in Education

Received: 12 August 2021
Accepted: 10 May 2022
Published: 03 August 2022

Citation:
Liston M, Morrin AM, Furlong T and Griffin L (2022) Integrating Data Science and the Internet of Things Into Science, Technology, Engineering, Arts, and Mathematics Education Through the Use of New and Emerging Technologies. Front. Educ. 7:757866. doi: 10.3389/feduc.2022.757866

This paper reports on the implementation of a collaborative approach to STEAM (Science, Technology, Engineering, Arts, and Mathematics) education within the context of a college of education and an elementary school in Ireland. The project is novel in that it explores a transdisciplinary approach of supporting STEAM education in a school, using data science and an Internet of Things (IoT) based Environment Monitoring System. This case study contributes to an emerging field of research within STEAM that is informed by practice with emphasis placed on the value of collaboration and transdisciplinary pedagogical approaches. The multi collaborators included lecturers from a college of education with expertise in STEM and Visual Arts education, creative professionals (artists, scientists, and architects), teachers, students, and children. Encompassing all the mentioned stakeholders was important and placed transdisciplinarity at the core of the learning. Qualitative data was collected using questionnaires, focus groups and interviews to research how the participants interpreted their experiences and what meaning they attributed to their experiences. It was found that a program of STEAM education integrating new and emerging technologies with data science and the IoT can promote and encourage the delivery of a transdisciplinary model of STEAM education and the overall reconceptualization of how individual subject areas are taught at elementary level. Innovative data capturing technologies, exploring real-life data within their local educational contexts can positively impact children and teachers' knowledge and skills in STEAM supporting the development of artistic concepts, engineering habits of mind, imagination, and creativity. The success of the project can be attributed to the collaboration between various stakeholders in the design and implementation of the project. This paper has provided valuable insights into teachers', scientists', and artists' perspectives, children's experiences, and the role of innovative technology in STEAM education.

Keywords: STEAM, professional development, IoT, innovation, data, outreach

INTRODUCTION

In this ever, evolving technological world, it has become increasingly necessary to approach big societal, industrial, and ecological questions through transdisciplinary ideas, attitudes and skills. The World Economic Forum has reported that by 2025, automation and machine working will be prominent in all places of work. Data science, Artificial Intelligence (AI), content creation and cloud computing are now the top emerging professions for the "jobs of (not only) tomorrow" but the "jobs of today" (World Economic Forum, 2020). Against this background, education must do more to ensure today's students become tomorrow's skilled thinkers.

Reports, strategies and action plans highlight the importance and need for people with STEM (Science, Technology, Engineering and Mathematics) skills such as creativity, problem solving, critical thinking, and communication skills (Augustine et al., 2010). There are many governmental strategies on innovative STEM pedagogies being implemented right across the world, focusing on inquiry-based problem solving, using digital technologies. However, curricula can become outdated very quickly with the fast pace of change in the world of STEM. Equally, the curriculum should consider how children currently engage with technology (socially and cognitively) and integrate technology more creatively into teaching and learning experiences. In addition to the previous arguments around future skills, education involves more than just providing a future workforce, it needs to value and nurture the dispositions of young people in order for them to thrive in life. More emphasis must be placed on innovation, problem solving, creative thinking, digital skills and realized through a collaborative approach at all levels of education (Wagner, 2012; Wagner and Dintersmith, 2015).

Science, Technology, Engineering, Arts, and Mathematics Education and Transdisciplinary Practice

Creativity and critical thinking have been shown to contribute in important ways to the factors that underpin teaching and learning such as risk taking, questioning assumptions, and reframing problems (Getzels and Jackson, 1962; Perkins, 1995; Sternberg, 1996). Arts-based learning has emerged as an interdisciplinary and transdisciplinary approach to STEM education, that develops creativity, design, and innovation among STEM learners (Henriksen, 2014). Therefore, arts in education contribute to learning in considerable ways by developing cognitive abilities, critical thinking, problem solving, confidence, motivation, and communication skills (Blatt-Gross, 2013; Adams, 2014; Crossick and Kaszynska, 2016; Lucas, 2016).

Learning environments that are innovative, support children in building 21st century skills, to become flexible, self-directed, social, productive, and responsible citizens (MacDonald, 2003; Gregory and Kuzmich, 2005). STEAM is an innovative educational approach which promotes interdisciplinary and transdisciplinary learning across the STEM disciplines and the arts, allowing students to increase their knowledge and understanding of key scientific, technological, engineering and mathematical concepts through making connections within and across disciplines by emphasizing elements of design and creative planning (Connor et al., 2015; Henriksen et al., 2015; Morrin and Liston, 2020). Transdisciplinarity is described as a practice that transgresses and transcends disciplinary boundaries and has the potential to respond to new demands in education. This potential springs from the characteristic features of transdisciplinary approaches to teaching and learning. These include problem focus (research originates from and is contextualized in "real-world" problems), evolving methodology (the research involves iterative, reflective processes that are responsive to the particular questions, settings, and research groupings) and collaboration (including collaboration between transdisciplinary researchers, disciplinary researchers and external actors with interests in the research) (Russell et al., 2008). Arts infused learning can enhance learning STEM through design and cross-disciplinary collaboration. Core elements of creative thinking that relate to STEM education also include innovation, originality, applicability, appropriateness, and usefulness. Engagement in the arts can also motivate and help shape reflective individuals and may promote engaged active citizenship (Crossick and Kaszynska, 2016).

There can be many challenges to the design and delivery of STEAM education. Educators and education systems have not fully figured out how to deliver an interdisciplinary STEM and STEAM approach (Ejiwale, 2013; Thompson et al., 2018). Consequently, educators struggle with a clear conceptualization of STEAM and how the disciplines might be connected (Guyotte et al., 2015; Quigley and Herro, 2016; Quigley et al., 2017, 2020). Some current practice has shown that STEAM lessons are not truly integrated and can involve plugging art into the STEM fields and lack understanding of how to approach teaching STEAM in a transdisciplinary manner (Piro, 2010; Herro and Quigley, 2017). From the authors' experiences, STEAM activities in schools and educational outreach settings too often focus on children's so called "soft skills," such as problem-solving, creativity, and communication skills. Monkeviciene et al. (2020) also found that little attention was given to the development of mathematical, technological, and engineering concepts and skills during STEAM activities in early childhood settings.

One reason for this may be that there are not enough pre- and in-service professional development programs, which may lead to a lack of confidence in their ability to teach STEAM (Shin, 2013; Lee, 2014). We believe that there is a need for high-quality professional development of teachers, in how to effectively incorporate interdisciplinary and transdisciplinary STEAM lessons and activities into their teaching (Herro and Quigley, 2017).

Another barrier to the successful implementation of STEAM education in schools is the limited availability of STEAM teaching materials and strategies, which in turn affects if and how STEAM is taught (Geum and Bae, 2012). Generally, educators are designing and teaching lessons based on readily available online STEAM teaching resources and books, however, from the authors' experiences many such activities are usually a science lesson with one other subject area added into the lesson or at the end of a lesson. For example, a lesson where children make a lighthouse learning about circuits and electricity and then at the end of the lesson, carry out some "art and craft" and build a structure of a lighthouse around the circuit with no explicit exploration of artistic and mathematical concepts and skills and the engineering design process. Yet they are still being categorized as STEAM lessons. Many STEAM activity books and published teaching resources do not encompass elements of all the different disciplines involved in STEAM education. STEAM education is not just S&T or S&E or S&A or S&M it is S&T&E&A&M. Technology, art, mathematics, and engineering, must take a more prominent role in STEAM education, as their interdisciplinary nature can greatly strengthen STEAM lessons (Quigley and Herro, 2016; ITEEA, 2020). There is much more to integrating STEAM disciplines than simply teaching two disciplines together or using one discipline as a tool for teaching another (Gerlach, 2012; Bryan et al., 2016). The issue is due to there being so many different interpretations of integrated STEAM education (Rennie et al., 2012; Honey et al., 2014; Moore and Smith, 2014; Quigley and Herro, 2016).

Science, Technology, Engineering, Arts, and Mathematics is a new and evolving pedagogy in education. Recent research exploring STEAM education recommends that future STEM education strategies should include STEAM methodologies in the classroom (Morrin and Liston, 2020). This paper presents an educational program of STEAM education, involving the design and delivery of a transdisciplinary project entitled "STEAM-ED," where the arts and the sciences were not treated or taught separately, but rather combined in a transdisciplinary manner. The STEAM-ED project involved the design and implementation of an approach to STEAM education delivered to pre-service and in-service teachers addressing these key challenges facing teachers in the delivery of STEAM at elementary level. The project is unique and novel in that it explores a transdisciplinary approach to supporting STEAM education in a school, through the use of data science and IoT based Environment Monitoring System.

Data Science and Technology in Science, Technology, Engineering, Arts, and Mathematics

Big data, machine learning, and the IoT were the leading educational technology trends of 2019. The IoT describes the network of physical objects, i.e., "things" that are embedded with sensors, software, and other technologies for the purpose of connecting and exchanging data with other devices and systems over the internet. A "thing" can refer to a connected medical device, a biochip, a solar panel, a connected automobile with sensors that alert the driver to a myriad of possible issues (fuel, tire pressure etc.) or any object, outfitted with sensors, that has the ability to gather and transfer data over a network.

In a society where big-data sets are continuously being captured and extracted from multiple sources, there is a pressing need for data scientists and engineers, coders, data visualization specialists and data analysts, that can process, store, analyze and visualize data. As a result of this move toward digital technologies, data and IoT, it has become increasingly evident that artists are continuously evolving and intertwining emerging technologies and media within their art practices (Shanken, 2002). This work involves science, mechanical engineering, computer programming and artistic concepts in producing code-generated artwork and interactive installations. Nowadays artists are also engaging with data analytic tools and computational techniques at a much deeper level in their digital art practices with the rise and rise of AI and the IoT (Stark and Crawford, 2019).

Science, Technology, Engineering, Arts, and Mathematics education can benefit citizens in a world in which data science and technology are becoming more and more prevalent. Technology in STEAM education must be embedded in the problem-solving process, where art practices and ways of sense-making can be applied to support problem-solving in science and technology (Land, 2013). The OECD (2016) argues that innovation in education and educating for innovation can only be achieved through novel digital technologies in the classroom. In recent times there has been a growing body of research on STEAM teaching practices, with a limited amount of research being carried out on how teachers can integrate essential skills, such as creativity, problem solving, innovation, communication, analysis of data and collaboration, into STEAM education through the use of technology. Baig et al. (2020) carried out a systematic review of 40 research publications, published from 2014 to 2019, based on big data in education. They found that only 10% of the studies were on the integration of big data into the curriculum theme. There have been many publications on gathering data in STEM lessons, using, for example, satellite data, aerial photography, soil probs etc. (Hotchkiss and Dickerson, 2008; Davis, 2017). However, there has been very little work published on IoT and data science in STEAM education.

The study of Data Science should begin at elementary level. Many argue that it should even begin at pre-school level (Martinez and LaLonde, 2020). Children are continuously gathering data throughout their school day, whether they are making observations, or recording observations, words, and numbers and/or comparisons. They record and present data by drawing, listing, labeling, filling in tables and graphs, and using this data to find patterns, make predictions, draw conclusions, and display or share their findings. However, data science is a relatively new pedagogical approach in elementary education. The IoT and the scale and quantity of data being generated and captured via digital technologies can bring many opportunities to educators and education (Franklin et al., 2007). The OECD maintain that technology-based innovations in education can reshape the teaching and learning environment (OECD, 2016). This can be achieved by opening up the school classroom to the IoT through both the digital world and the physical and social environment. IoT uses data to transform the way we live, work, and play. In this paper, the authors propose that IoT projects involving the gathering of big-data sets captured by sensor technologies can provide a unique opportunity for teachers and children to engage in context-based STEAM education.

The Context of the Study: Establishment of Science, Technology, Engineering, Arts, and Mathematics Expertise in the Development of Transdisciplinary Science, Technology, Engineering, Arts, and Mathematics Practices

The STEAM-ED project was designed and developed to bring an innovative program of STEAM education involving data science and IoT to pre-service teachers within a college of initial teacher education and to children and teachers in an elementary school. This was achieved by establishing a multi-disciplinary team (the STEAM-ED team) involving artists, architects, scientists, engineers, and experts in the area of STEM and visual arts education. As previously stated, STEAM is an evolving concept and very much a new development within teacher education and elementary education.

The initial stages of the project involved undergraduate elementary education students in their fourth and final year of their studies. This included two cohorts of students studying two separate specialisms: STEM and Visual Art, across different departments (Arts and STEM) within a faculty of education, at third level education (**Figure 1**, Phase 1). The premise of this project was to create a transdisciplinary approach to teaching and learning to improve teaching practices and provide an authentic, fresh and inclusive approach to teaching STEM and arts education (STEAM). STEAM-ED attempts to blur the boundaries of disciplines by sharing common investigations to respond to the same concept and context, without any hierarchy and collaboration of all experts. This was achieved by de-coupling the discipline from its original context, in order to open up new possibilities for viewing and experiencing the same phenomenon (Burnard et al., 2021). In other words, we identified transdisciplinarity, as an approach where knowledge is sought and connected, across and beyond disciplines. For the purposes of this study the authors adopted the following description of transdisciplinary STEAM education: the blending of disciplines, in order to develop a deep level of understanding of concepts from a variety of disciplines and how they are connected (Herro and Quigley, 2017). This involved exploring STEM concepts through art and perception and using the visual arts and design to provide a diverse lens on the structure of scientific and artistic work, as an integrated approach providing different perspectives, and the generation of diverse and innovative ideas (Silverstein and Layne, 2010). The project pays particular attention to the transformative learning potential of STEAM education, where neither the STEM nor the arts are privileged over the other but that they are both treated equally in the delivery of STEAM. Mejias et al. (2021) states that STEAM needs to be conceptualized as both pedagogical and mutually instrumental, combining arts and the STEM fields as valued and engaged coequally.

The STEAM-ED project (funded by Science Foundation Ireland [SFI]) was multi-disciplinary in nature. Here, experts in STEAM were established to create a STEAM-Ed team which included artists, architects, scientists, engineers, and STEAM education experts. Collectively the STEAM team researched, designed and delivered an education program which involved creating an authentic STEAM educational experience for pre-service and in-service teachers who in return delivered STEAM activities to children between the ages of 4–12 years (**Figure 1**, Phase 2&3). The overall aim was to link key concepts in the areas of STEM and the arts while linking the activities back to the school and their curricular goals (Gomes and McAuley, 2013; Wilkerson and Haden, 2014).

Research shows that outreach activities have attributed their success to involving a network of stakeholders, including experts in STEAM education, along with teachers, school communities and children in the design and implementation of their (European Commission, 2007; Stocklmayer et al., 2010). Also, many reports strongly emphasize the need for educational outreach programs to partner and collaborate with higher-level educational institutions (Henriksen et al., 2015; Jose et al., 2017). The values of collaboration and inclusivity were central to the STEAM-ED project as the aim of the project was an attempt to break down disciplinary boundaries and see the potential of merging STEM and visual art that identify key concepts and goals across the areas.

The STEAM-ED Project

The project was implemented through four interconnecting phases across the continuum in teacher education, i.e., pre-service and in-service teachers and elementary education of children:

- Phase 1: Professional development in STEAM
- Phase 2: STEAM Educational Outreach
- Phase 3: Design Thinking
- Phase 4: An IoT based Environment Monitoring System.

The project explored how STEAM can be implemented into a Bachelor of Education (Elementary Teaching) program and sequentially delivered across an entire school community, by working with teachers, children, STEM and Arts Education experts, and the creative community to design and pilot a STEAM education program, involving innovative pedagogies, with a focus on technology and data science. **Figure 1** gives an overview of the aims and outcomes of each phase. (Click on link to view examples of Student journals[1] and an example of a STEAM scheme delivered in an elementary school[2]).

For the purposes of this paper, the authors will report on the fourth phase of the project which involved the integration of both physical and digital technologies (micro controllers, sensors, interactive software and web development tools) into STEAM education (**Figure 1**, Phase 4).

[1]https://www.youtube.com/watch?v=W_vYsNXQesQ
[2]https://www.youtube.com/watch?v=3-m5TxgLOmU

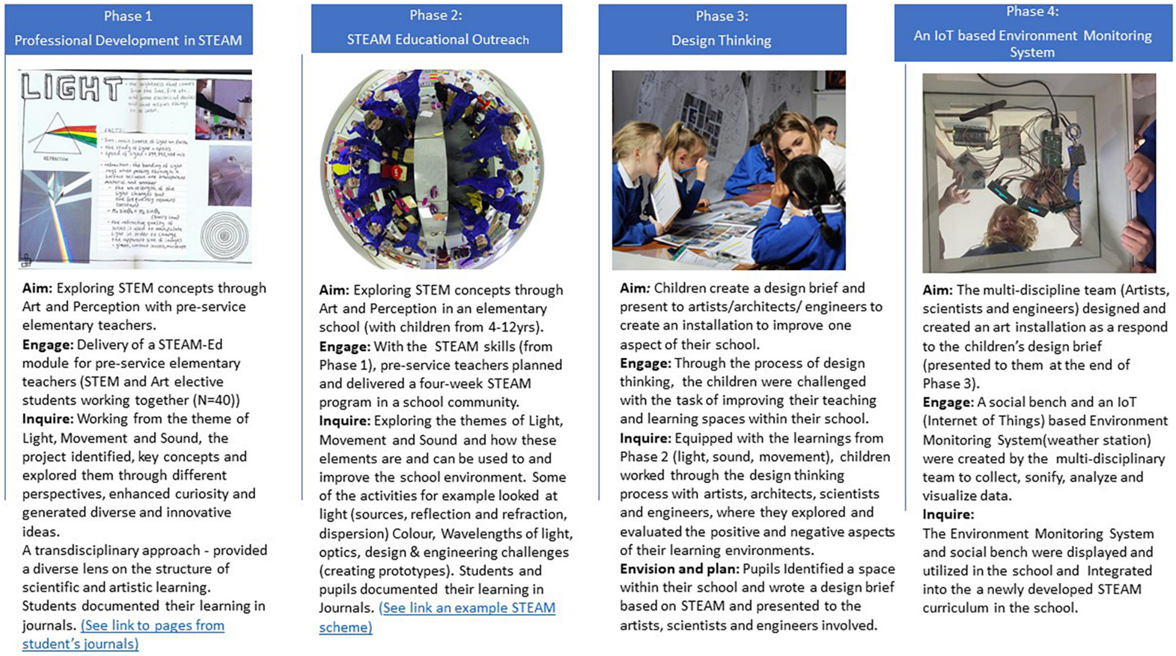


FIGURE 1 | Four stages of the STEAM-ED Project. Image in phase 3 panel from Morrin and Liston (2020).

RESEARCH METHODOLOGY

The research methodology involved a case study approach, allowing for the development of a detailed analysis of how the STEAM-ED program integrating new and emerging technologies influenced the teachers' practices and engaged children with data science and the IoT in an elementary classroom (Merriam, 1998; Cohen et al., 2000).

The study applies Merriam's (1998) description of a qualitative case study, i.e., a holistic description of the STEAM-ED project (a bounded phenomenon) occurring in a specific elementary school (within a particular bounded context). The case study approach taken was particularistic (focusing on the STEAM-ED project), descriptive (providing in-depth descriptions from varied and multiple perspectives) and heuristic (interpreting the participants' experiences and what meaning they attributed to their experiences).

A pragmatic approach was taken to the design of the methodology (Tashakkori and Teddlie, 2003). Questionnaires, focus groups and interviews were used to collect data at the end of this case study providing in-depth descriptions from varied and multiple perspectives (Eisenhardt, 1989). Qualitative data was collected in order to explore how the participants interpreted their experiences and what meaning they attributed to their experiences (Merriam, 2009). Multiple methods of data generation were used to ensure triangulation (Cohen et al., 2000).

These methods were designed based on the two main research questions:

(1) How can a STEAM education program integrating new and emerging technologies influence teachers' practices and engage children with data science and the IoT in an elementary classroom?

(2) How can a collaborative multi-disciplinary researcher/practitioner partnership inform the design and delivery of STEAM education?

The case study approach allowed the researchers to obtain valuable insights into teachers', scientists', and artists' perspectives, children's experiences and the role of innovative technology in STEAM education. This unique and novel interpretation of STEAM explored a transdisciplinary approach of supporting STEAM education in a particular bounded context, through the use of data science and an IoT based Environment Monitoring System.

Qualitative data was analyzed using bottom–up or inductive data-driven thematic analysis, applying Braun and Clarke's (2006) six-step framework to thematic analysis (Step 1: Become familiar with the data, Step 2: Generate initial codes, Step 3: Search for themes, Step 4: Review themes, Step 5: Define themes, Step 6: Write-up). The categorization of codes into themes was completed by two researchers to increase rigor. Two rounds of coding (reviewing the initial codes and themes generated) were completed prior to identifying dominant and distinct semantic themes. Codes were assigned to portions of data and later organized into categories which were then presented in a series of themes (Saldaña, 2021).

Children's Questionnaires and Focus Groups

Qualitative data was gathered using a questionnaire (N = 20 children) and focus groups [N = 20 (4 × 5) children] to explore the children's experiences of the IoT based Environment Monitoring System. The questionnaire allowed children to answer the questions on their own, in their own time and in a non-invasive way. The focus groups occurred after all of the children had filled in their questionnaires on the same day. The focus groups (N = 4) involving five randomly chosen children from a list of names, were moderated by the two experts in STEAM education managing this project. The focus groups were used as a means to probe deeper into their experiences, allowing for an open dialogue among peers (Morgan, 1988). Focus groups were also chosen as a method of data collection to complement data collected through the children's questionnaires, as peer responses can provide cues for others (Morgan, 1988; Kreuger, 2009). It was found during this study that this in turn led to obtaining diverse ideas and perceptions from the children. A convergent design to the data collected from the children allowed for the merging of results from the questionnaires and focus groups (Creswell, 2014).

Stakeholder Interviews

At the end of the project, semi-structured interviews were conducted by an independent bystander with the STEAM education experts leading this project (N = 2), the contemporary artists that designed the IoT system (N = 1) and a class teacher (N = 1) that incorporated this innovative technology into her teaching with a group of children (N = 20) aged between 11 and 12 years old over a 2-month period. The semi-structured interviews, involving descriptive and experience questions allowed for detailed discussion around the participants' experiences and thoughts around the implementation of a STEAM education program integrating new and emerging technologies at elementary level (Patton, 2002). Interviews rather than focus groups were conducted with the above participants as they were all coming to the project from different perspectives and the researchers wanted to capture these unique insights by interviewing them individually. The interviews wanted to capture the meaning of what each of the interviewees said (Kvale, 1996). The interviews were designed by the researchers but conducted by an independent gatekeeper, from the faculty that had been informed about the project, to ensure that the interviewees were not led in any way.

Introducing Data Science in an Elementary Classroom Through an Internet of Things Based Environment Monitoring System (Phase 4 of STEAM-ED Project)

Collecting Data Using Sensor Technologies

An IoT based Environment Monitoring System (weather station) was created by a contemporary artist to collect, sonify, analyze, and visualize data. (Note: It may be useful to note that the Environment Monitoring System evolved due to the skillset of the specific artists involved in the project and their interpretation of the design brief created by the children). This included sensors to collect data on light, humidity, temperature and sound from the school's surrounding environments. The sensors are connected and controlled using Arduino board technology. Arduino boards are open hardware development boards that can be used to design and build devices that interact with the real world (**Figure 2**). The four sensors were placed at the main entrance of the school and the microcontroller on the board was programmed using the Arduino programming language to collect data on light, humidity, temperature and sound levels of the environment. Three small LCD screens display the current, real-time sensor information for temperature, humidity and sound level (**Figure 2**). Children can read the values of the environmental measurements at any time throughout the day (**Figure 3**).

The real-time data from the four sensors was then sent to a website which was developed using ThinkSpeak.com to store and visualize the data being collected using a sigfox IoT connection to the internet, making the school part of the IoT (**Figure 4**). Visualizations of the data are created on the ThinkSpeak.com using Matlab. In Matlab a wide range of graphical displays are programmed to uncover and extract meaning from the data. Online representations of the real-time data from the sensors in the school are displayed on a designated website (**Figure 4**).

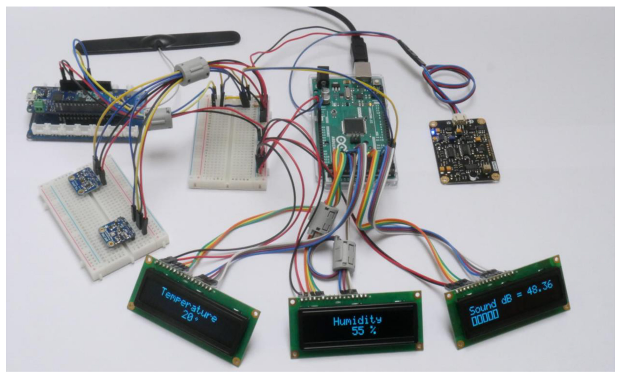


FIGURE 2 | Sensors and LCD Displays (Morrin and Liston, 2020).

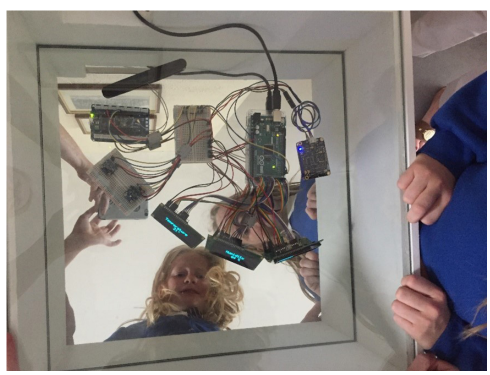


FIGURE 3 | Children looking into the Adruino boards which are connected to sensors, collecting data on light, humidity, temperature, and sound levels of the school environment (Morrin and Liston, 2020).

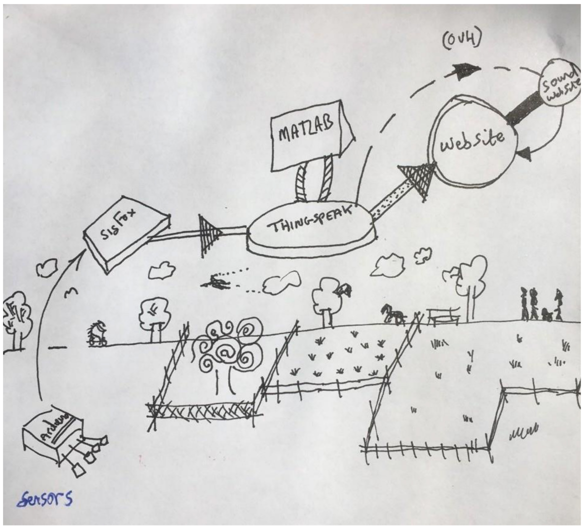


FIGURE 4 | Outline concept sketch for connecting school to IoT.

Outputs From the Internet of Things Based Environment Monitoring System: Raw Data and Data Visualization

The real-time data was used to create visual representations and a musical score on the website. The charts are organic, i.e., the data for each chart is updated with the latest real-time information every 15 min. They can view this data on their classroom computers and on a number of wall-mounted electronic tablets displayed in the school corridors. The four elements (light, humidity, temperature, and sound) over a 48-h period are represented on one chart (**Figure 5**). The current readings from the school are also displayed under the "Now" heading. Looking at this chart it is possible to compare the different elements over a 2-day period.

Each of the environmental elements can be viewed by the children and teachers in four different representations (light, sound, temperature and humidity – 16 representations in total). For example, the temperature data can be viewed via either a line graph, heat intensity map, area graph or bar chart (**Figure 6**). Humidity is represented in line, pie, trend charts and by a gauge monitor. Sound is represented by a bar and trend chart and sound intensity map. The light data is represented in a line and bar chart, a light intensity map and a radial graph (**Figure 7**). The children and teachers also have access to the raw data.

Outputs From the Internet of Things Based Environment Monitoring System: Sonification

An exciting development within the project was that the artist involved in the project pushed their own creative boundaries by programming the environmental live data to create a musical score and orchestrate a continuous soundtrack. This involves the soundtrack being emitted through speakers in the main reception of the school (**Figure 8**). The musical score was developed based on the environmental readings in the air (light, sound, humidity, and temperature). For example, if there were low levels of humidity in the air, the music was of a slower tempo and rhythm and lower pitch and if there is high humidity in the air the music had a much higher pitch and tempo. This incorporated many concepts around sound (pitch, frequency, loudness, and wavelength) which can be further explored in the classroom. The visual soundscape was created through a web editor (Tone.js/p5.js). **Figure 8** provides an overview of how the musical score is created through the live data.

Incorporating the Internet of Things Based Environment Monitoring System Into Teaching and Learning

Professional development supports were provided by the STEAM team to guide teachers on how to creatively engage with STEAM concepts as well as how to design and deliver activities based on the IoT based Environment Monitoring System data within their classrooms. The teachers integrated both physical and digital technologies (micro controllers, sensors, interactive software and web development tools)into their teaching. The teachers also worked with the children themselves in developing STEAM lessons, deciding what to explore and investigate using the environmental data and how the data could be represented and visualized, incorporating concepts of science, art, technology and mathematics. The IoT based Environment Monitoring System was used as a vehicle to investigate a variety of problems and solutions (Land, 2013). These lessons were also designed to develop the children's understanding of how to work with data and how data can be represented and communicated in everyday life in an engaging and interesting way. The learning was also supported by exploring online resources for instance how contemporary artists (such as Miebach, Pelto, Project Ukko; Lupi and Stefanie) explore data visualization and how IoT systems are incorporated into current practice. The results of this study are based on how the IoT based Environment Monitoring System situated the learning in the context of the teachers' and children's school environment by providing children with numbers in context as recommended by Cobb and Moore (1997) and Putnam and Borko (2000).

RESULTS

The five main themes generated during the process of analyzing the data are as follows:

(1) Transdisciplinary Learning.
(2) STEAM Teaching and Learning.
(3) Inclusive STEAM Education.
(4) Attitudes to Data Science.

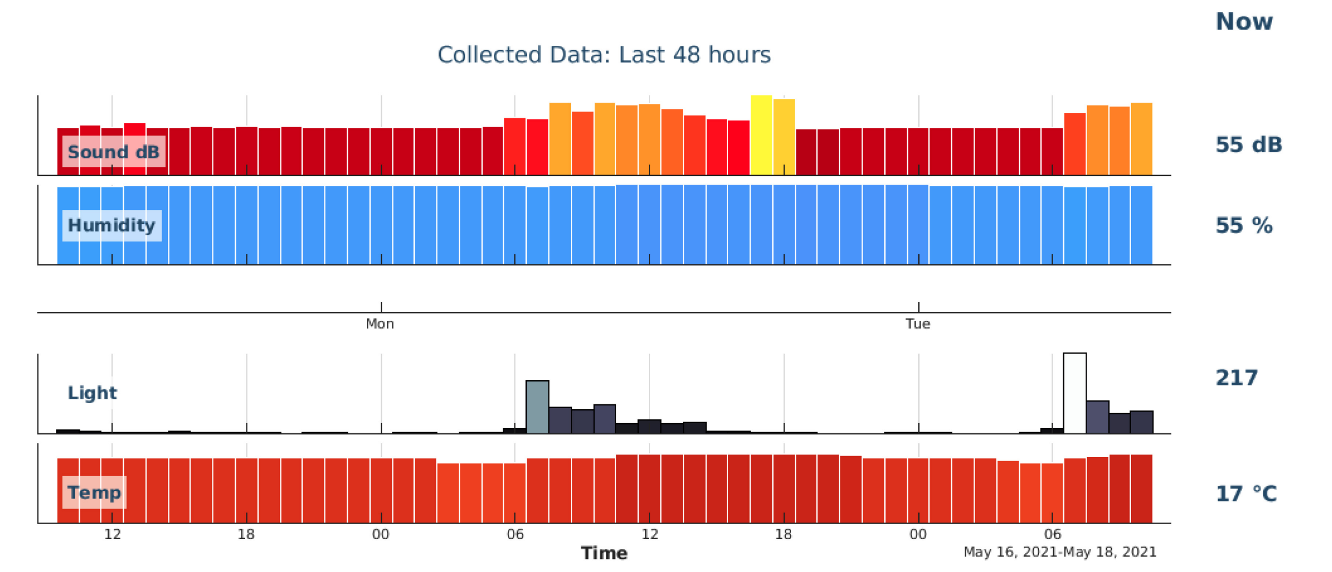


FIGURE 5 | Chart displaying information for the previous 48 h.

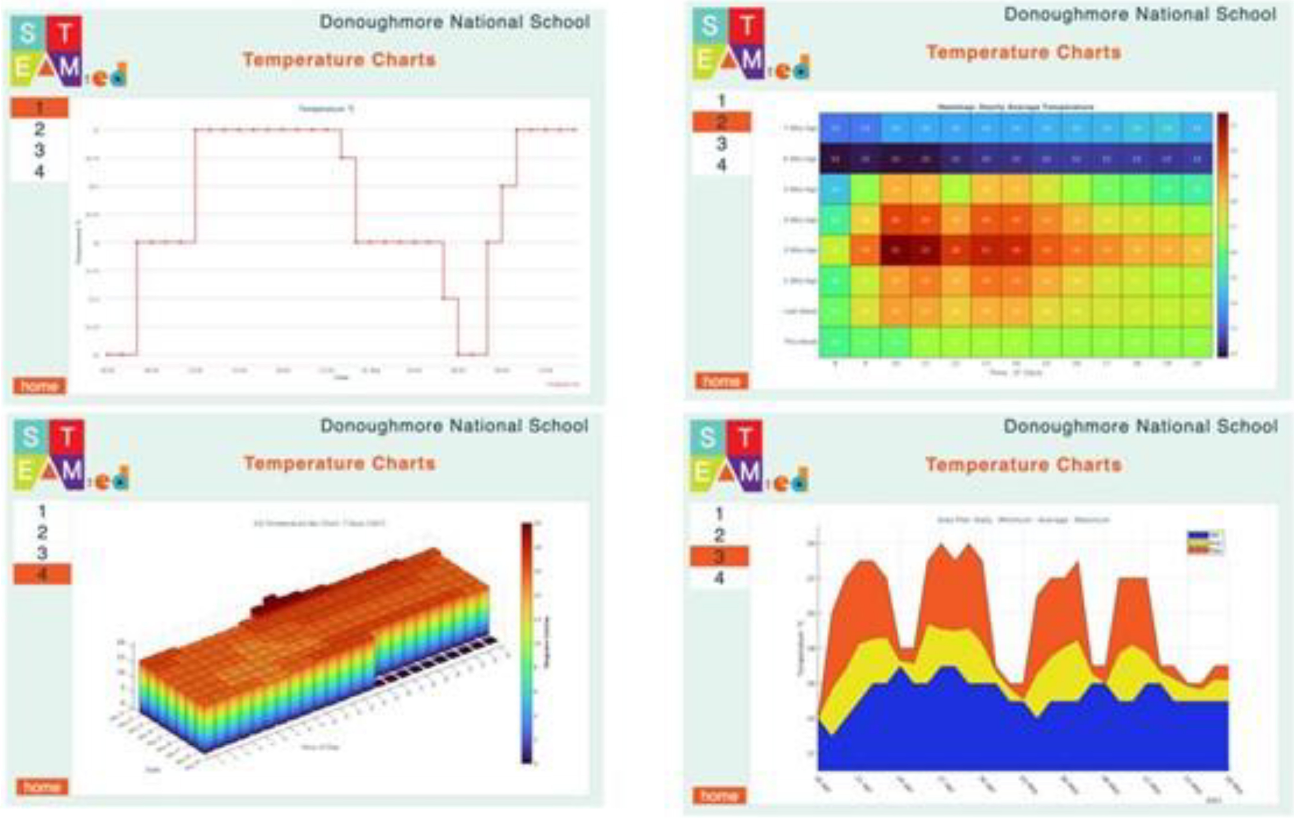


FIGURE 6 | Temperature data represented on a line graph, heat intensity map, area graph, and bar chart.

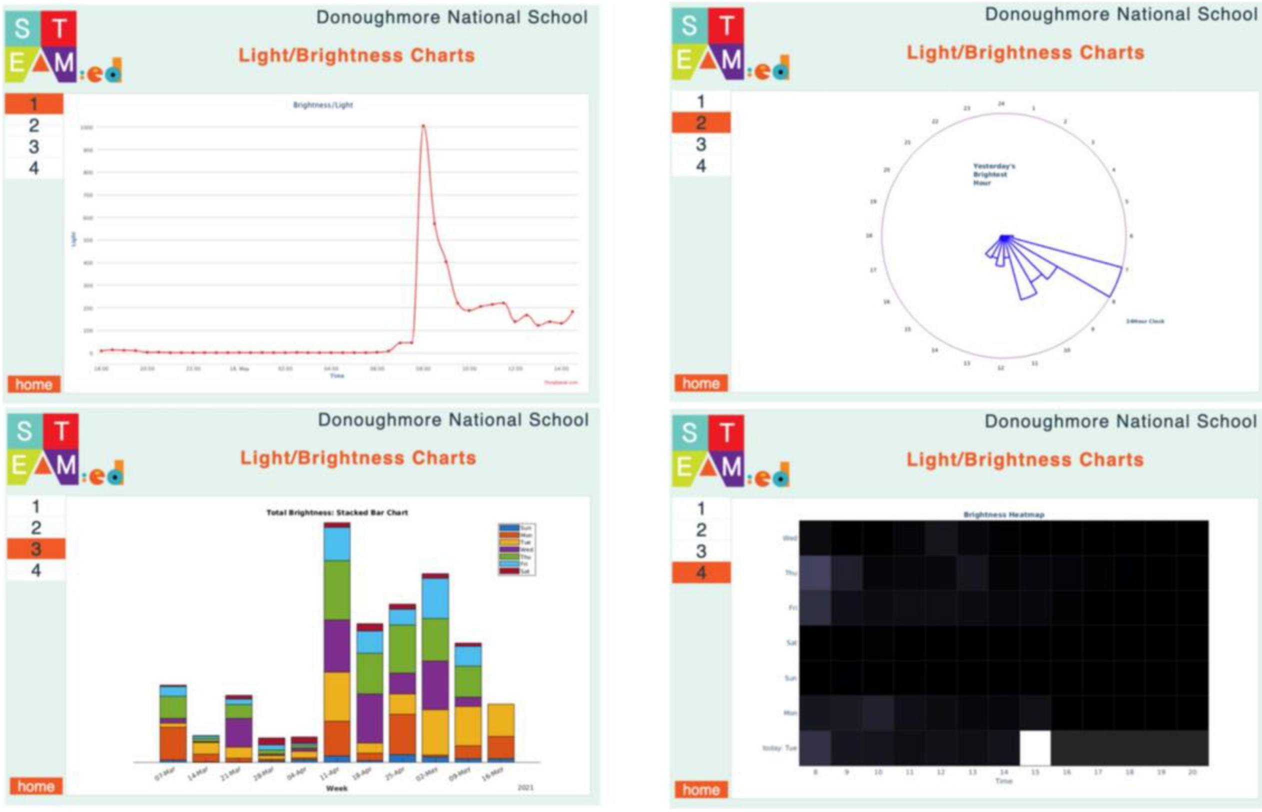


FIGURE 7 | The light data is represented in a line and bar chart, a light intensity map and a radial graph.

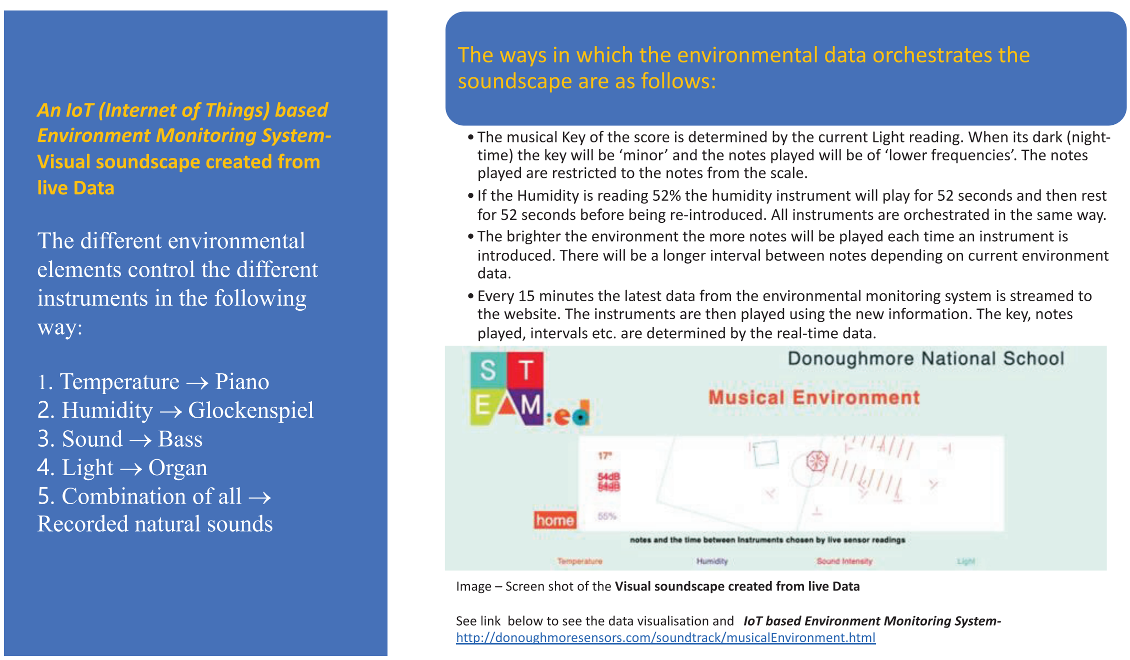


FIGURE 8 | Creating a musical score with data.

(5) Professional Development.

Transdisciplinary Learning: A Program of Science, Technology, Engineering, Arts, and Mathematics Education Integrating New and Emerging Technologies With Data Science Can Promote a Transdisciplinary Approach to Education

The class teacher adopted a transdisciplinary approach to her teaching and learning when integrating the weather station into her elementary classroom. The activities included the development and practice of concepts, skills, habits of mind and attitudes from art, science, technology, geography, mathematics and music (**Table 1**). A constructivist approach to teaching and learning was also applied, building on the children's prior knowledge and experience of STEAM (light, sound, and movement) from the previous phases of the STEAM-ED project. The data presented in **Table 1** on the transdisciplinary concepts explored in STEAM lessons was produced by analyzing the following: children's questionnaires and materials produced in the classroom; teacher's interview responses and teaching resources developed for the delivery of the STEAM lessons.

The interviews, focus groups and questionnaires explored the pedagogical approaches used in delivering lessons using data collected by the weather station. The pedagogical approaches mentioned by the teacher and children are listed in **Table 2**. From the children's and teacher's descriptions of the STEAM lessons, it was evident that the lessons centered around transdisciplinary problem-based learning, technology, multiple lines of inquiry and problem solving. The teacher stated that "*this data has allowed me as the teacher to teach lessons using this data in a very cross-curricular manner.*"

The teacher was asked how the weather station had informed her teaching. She noted how impactful it was to have access to real data and numbers in context: "*Rather than using data that I pull from textbooks or from online to form the basis of a lesson, I now have realistic, relevant data that appeals to my students because it is centered around our school community.*"

She also noted that the live and ever-changing data sets being captured by the weather station made data science engaging and interesting for the children: "*The weather station is live and is dynamic. If the data being recorded was very similar from day to day, week to week etc. it would not be as useful. However, as it is very seasonal, the daily changes make it interesting for the children to keep track of.*" Comments from interviews with stakeholders in the project echoed the same sentiments for themselves when engaging with the project: *"For me personally it makes learning so much more interesting and all the subjects within STEAM more enjoyable the fact that the data was live you could almost feel and embody the data, this made the learning so much more valuable."* (Expert in Visual Arts Education).

TABLE 1 | Transdisciplinary concepts explored in STEAM lessons using an IoT based Environment Monitoring System.

Subject area	Transdisciplinary links using the weather station*
Science	Exploring concepts of: Light: energy, light (sources, reflection, refraction, dispersion), color, wavelengths of light, shadows. Sound: energy, sound (sources of different sounds, reflection, pitch, loudness), measuring sound, sound waves, transmission of sound. Temperature: energy, heat (sources of heat, absorption and reflection of heat), movement of heat, measuring temperature. Properties and characteristics of materials. Weather trends. Climate change. Measuring instruments.
Technology	Designing and creating prototypes, electrical circuits, Arduino boards, sensors. The use of iPads to access the data, interact with the data sensors and using the data to create graphs, animations and games. Visualization of data. Sonification of data. The use of technology to help children make sense of the world around them.
Engineering	The Engineering Design Process. Design, construction and improving the design of the weather station. Engineering new devices to add to their weather station. Designing objects that could affect the readings on the weather station, for example, blackout blinds.
Art	Developing the concept of line, shape and space, color and tone, pattern and rhythm, space, balance, unity. Exploring positive and negative spaces created by the environmental measurements and graphs. Imagining – exploration of line graphs and imaginative concepts. Creative ways to represent data (line, shape, pattern, movement, spatial awareness, color and tone). Exploration of color and tone through the temperature heat map. Psychology of color – investigating how colors are associated with moods and feelings. Exploring how the environmental soundtrack can help the school to create an environmental mural, i.e., how does the school sound vs. how does the school feel.
Music	Exploring the cross-cutting concept of: Energy and sound, sources of different sounds, reflection, pitch, tempo, dynamic, structure, timbre, pattern, beat, rhythm (rhythmic and melodic patterns), loudness, sound waves and the transmission of sound. Developing music literacy by listening and responding and composing. Explore the expressive possibilities of a variety of sound sources.
Maths	Data [representing (graphs) and interpreting data]. Shape and space (patterns, spatial awareness, symmetry, lines, and angles). Spatial awareness. Measurement.
Geography	Weather and climate. Using weather instruments, units of measurement. Developing a sense of place. Climate change. Links to our community – question how data as information could be shared with the local community.

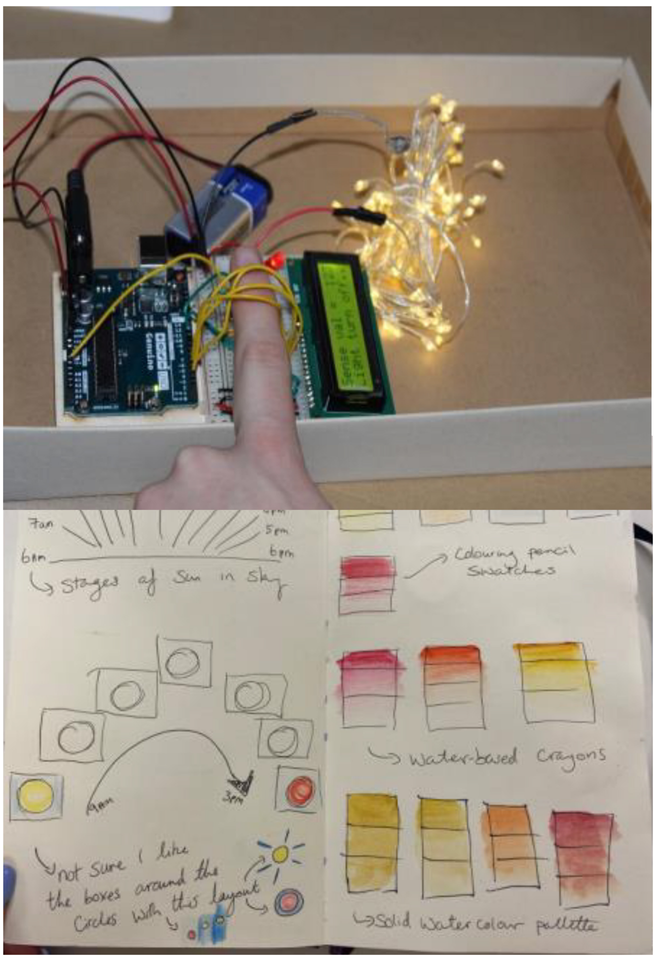
**The children and teacher referred to the IoT based Environment Monitoring System as the weather station.*

The teacher's integration of the STEAM lessons mirrored the goals of what the project wanted to achieve in the classroom. This was also echoed by the artist that reflected on the implementation of the IoT system into the teaching and learning within the school "*The station helps to introduce a variety of topics and enables engagement with different types of analysis. It makes information interesting and relevant through a practical application of STEAM-ED.*" (Artist).

Science, Technology, Engineering, Arts, and Mathematics Teaching and Learning: Data Capturing Technologies in Science, Technology, Engineering, Arts, and Mathematics Education and Its Associated Pedagogies Can Support the Development of Children's and Teachers' Knowledge and Skills

The teacher commented that working with the weather station allowed the incorporation of art into STEM education. Her comments mention many teaching and learning activities that they enjoyed when using sensors to teach STEAM. It was evident that she greatly enjoyed integrating art into their lessons when looking for patterns within data sets and visualizing data. As can be seen from her comments the multi-sensory nature of the lessons helped children to connect to data content in a more meaningful way: "*I think the live data is a great invention and great for doing art and science in school with the data,*" "*I enjoyed doing pictures and making pictures with the weather data,*" and "*I enjoyed working with the sound, it was calming. How the data created the sounds and songs from light, humidity, temperature and sound, great idea.*"

TABLE 2 | Pedagogical approaches used when integrating an IoT based environment monitoring system into STEAM lessons.



The children created artistic representations of the data collected by the weather station, which brought a personal element to their learning, where they drew from their imagination, "*making art with weather data*" and making *"my animation using the graphs."* The lessons achieved some very important objectives of arts education, specifically enabling the children to explore, clarify and express ideas, feelings and experiences through creative expressions using art and music, by providing a range of aesthetic experiences. Several children commented on using their imaginations "*I loved drawing from my imagination and working with the line graphs*" and *"we used the data to do some imaginative drawing."*

An emphasis was placed on creativity and design (Sharapan, 2012). The IoT based STEAM lessons allowed the children to express themselves in a variety of ways (Martinez and Stager, 2013). The lessons allowed for a great deal of creativity and originality (Maslyk, 2016). Activities such as creating pieces of art from data sets cultivated creativity and encouraged self-expression, two skills that are not traditionally associated with the STEM disciplines in education circles (**Figure 9**). The activities were designed to truly integrate art into STEM, not just adding art for decorative means, but to promote meaningful engagement and motivate the participants during design challenges involving thinking, making and doing which are the foundational components of technology and engineering education (ITEEA, 2020). Design during these activities also acted as a bridge between STEM and the Visual Arts (Bequette and Bequette, 2012). They posed and solved problems, made judgments about the construction process, and understood how to put things together (Doorley, 2014). These design challenges also contributed further to the development of the children's creativity and imagination.

Data Capturing Technologies in Science, Technology, Engineering, Arts, and Mathematics

The activities were child-centered where children took ownership of the lessons. During the brainstorming sessions at the beginning of every lesson, the children decided what and how they would use and work with the data. This allowed children to develop key STEAM skills such as looking for patterns, critical thinking, using models, communication and expression, interpreting and understanding visual representation and developing arguments from evidence reasoning. The teacher commented that *"I think engaging with the weather station has made me realize that the children can lead lessons and don't need me to learn!! Obviously, child-led and collaborative learning is always a*

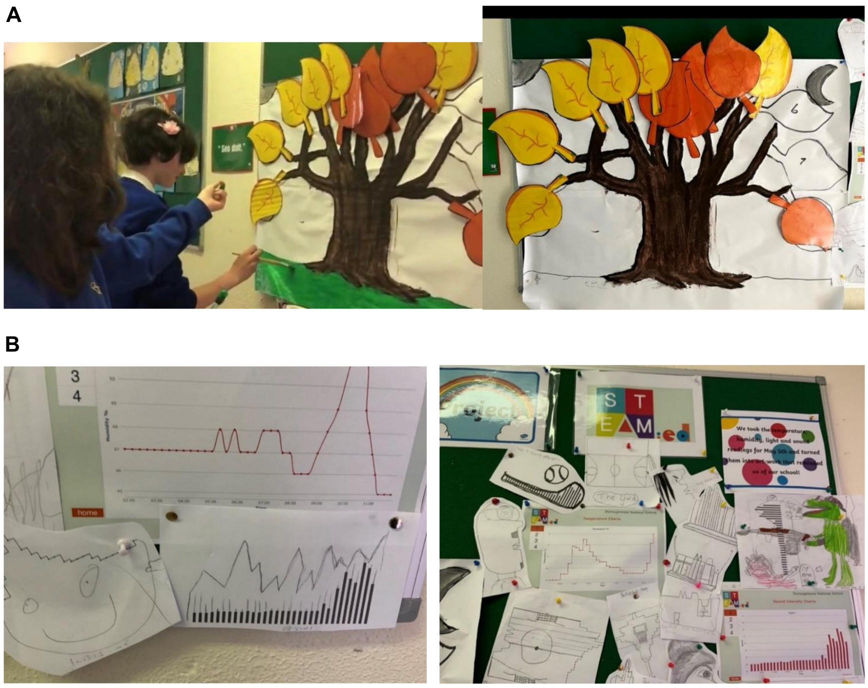


FIGURE 9 | (A) Creating a temperature tree using the temperature data collected from the IoT based environment monitoring system. **(B)** Examples of line art from the sensory weather station in the pilot school.

goal in the classroom but on many occasions here, I realized that by handing over the lesson to the children, the children displayed amazing problem- solving skills." As can be seen from the activities that were carried out, the children found the graphs and data on the temperature measurements the most interesting and wanted to explore temperature in greater detail. Therefore, the teacher focused on temperature in her lessons, where the children decided on what to explore using the data on temperature.

The children mentioned a variety of STEAM activities they used while analyzing, visualizing, and presenting the data. The activities included creating a "*temperature tree using colors and data*" (**Figure 9**), looking *"at the temperature heat map and creating our own chart," "using data to make a computer game"* (**Figure 10**), making *"line art using the graphs as inspiration,"* and composing music.

All of these activities involved finding patterns, creating visualizations, their imaginations and coding. They also composed their own musical pieces and their own graphical representations from the raw data collected, developing their artistic, musical, mathematical, technical, programming, and scientific skills of inquiry (**Figure 11**).

The children (N = 20) were asked what they thought about the live data collected from the sensory station. The majority of comments were positive mentioning that the live data was "*interesting*," "*creative*" and how different and innovative the technology was in the classroom. Their comments described the live data as "*interesting and cool" and "creative*" with particular mention to the *"way it continuously records the live data from 8am to 8pm."* They also mentioned that the weather station and sensors were new to them: *"I've never really seen a gadget like it before."*

FIGURE 10 | Using the environmental data collected using sensor technologies to code computer games.

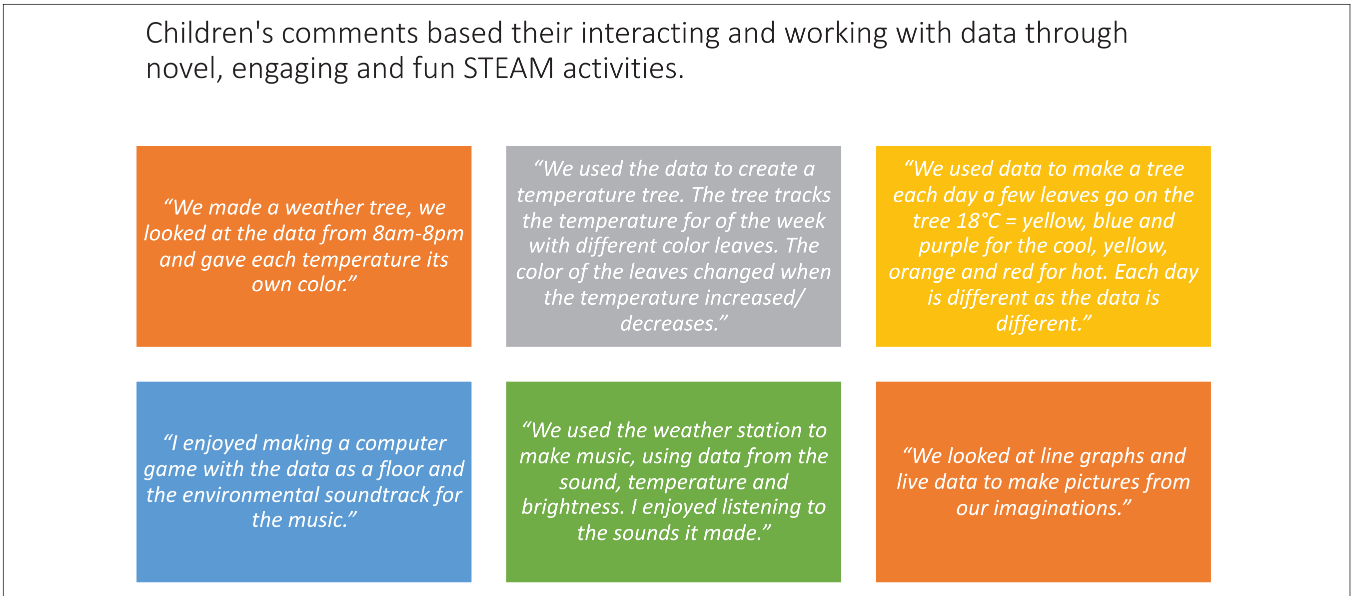


FIGURE 11 | Children's comments based their interactions with and working with data through novel, engaging and fun STEAM activities.

They mentioned the application of the live data in their responses stating that "*the live data is a great idea because you can see how hot/cold it is when we are in school and when we are not in school" and "when it comes to tracking the temperature and sound and seeing a massive difference in sound when school ends." They noted how they could impact the live data by for example "changing the noise levels to help everyone in the school.*"

The children were then asked if they had other ideas on how they could work with the weather station in the school. Their answers included further applications of data during mathematics, music and computer programming activities, for example: "*You could really get creative and make a character out of the data.*", "*Use the environmental soundtrack to make our own songs,*" and "*To make a game on the app. to draw in the younger kids.*"

The children also mentioned future scientific explorations using the data. This highlighted that the children were motivated by the lessons to continue exploring the live data being captured by the weather station in future lessons. Their comments also showed that they can see how the data collected by the weather station could be applied.

All stakeholders were asked for any suggestions on how the STEAM-ED project could be developed further in the school, many mentioned introducing and keep building on the technologies being used in the classroom, for example, introducing more sensors that can measure air quality in the classroom. This would concur with the children's desire to continue exploring the live data being captured, building their STEAM skillsets even further.

One comment from a child "*could the teachers use the station to teach maths,*" was interesting as it shows that the transdisciplinary nature of the STEAM lessons was a success in that the children were aware of the possibilities of learning key concepts and skills across a variety of disciplines and so did not recognize or categorize it as a "mathematics" lesson even though they carried out a significant amount of mathematical skills during the lessons. The teacher stated that "*I was apprehensive about whether or not the children would grasp the concept, or would it be a bit too abstract for them but as they always do – they rose to the challenge!*"

They were asked if they knew of anywhere else in everyday life, live data from sources are used. From their answers, it was evident that they developed an understanding of the application of data, data analysis and data visualization in the modern world (**Figure 12**). They mentioned many media sources, electronic platforms, websites and social media platforms they have experienced, for example, TikTok, Snapchat, YouTube, Kahoot, gaming, TV, Instagram, radio, Zoom, online games, competitions, talent shows and hospitals. However, one child when asked about their experience, mentioned that they didn't "*think it is that useful because I don't see the purpose of the*

FIGURE 12 | Children's feelings on using data in the elementary classroom that has been collected from an IoT based environment monitoring system.

data." This was an interesting finding, as the weather station was designed to ensure children were learning about data and the application of data within the context of their immediate school environment (Leavy and Hourigan, 2016). The inquiries that were carried out included purposeful activities and learning experiences (Bakker and Derry, 2011). This child did not demonstrate an understanding of how to use the data collected (Hiebert and Lefevre, 1986). Therefore, this finding may infer that a stronger focus was needed on the application of data and how data can contribute to society (Leavy, 2020).

The interviews, focus groups and questionnaires explored how the weather station impacted the development of STEAM skills in the school and on the stakeholders' professional development. The station was designed by a contemporary artist that describes the STEAM project as evolving over time and incorporating *"teaching of introductory data science so students can gain a basic understanding of how to work with data. To introduce students to some of the ways data can be explored and communicated in everyday life and to show data science that is fun to learn."*

The children were asked what skills they had developed while working with the live data from the weather station. They not only mentioned STEAM skills, but also understanding and attitudes in STEAM disciplines. An emphasis was also placed on creativity and design:

1. a. i. *"Using graphs, designing, classification, sorting, creating, observing"*
ii. *"Paying attention, classification, observation"*
iii. *"Designing and using my imagination and being visual"*
iv. *"I am now creative when using graphs"*

Many of the children in their comments described the weather station as an "*invention*" and "*gadget.*" They were intrigued by the design of the weather station and its components. During the lessons, they examined the design and construction of the weather and used the engineering design process during projects to look at improving the design of the weather station, engineering new devices to add to their weather station and designing objects that could affect the readings on the weather station. These lessons, therefore, developed the children's engineering habits of mind. "*During the activities, children thought and acted like engineers, artists, scientists and mathematicians*" (Expert in STEM Education).

Feedback from the teacher and children highlights that STEAM education and its associated pedagogies can support the development of artistic concepts, engineering habits of mind, imagination, and creativity. The children were asked what skills they developed during the project. They not only mentioned STEAM skills but also understanding and attitudes in STEAM disciplines. It was interesting to note, however, that when asked about the skills that they developed many of the children spoke first and foremost about the content and what they learned rather than the many habits of mind (Costa and Kallick, 2008) that they developed during the STEAM lessons. It was evident in their responses to their questionnaire and focus group questions that they had developed a variety of STEAM habits of mind. They spent much time creating, imagining and innovating, striving for accuracy, thinking flexibly, thinking and communicating with clarity, gathering data through all senses and applying past knowledge to new situations, all of which are included in Costa and Kallick's (2008), 16 habits of mind.

The data capturing sensors which were completely new technologies for this particular elementary school showcased how they were used to exploit the capabilities and possibilities of modern technologies to create high-quality learning experiences that foster students' innovation, creativity, communication and collaboration, critical thinking, and problem-solving skills. The children engaged in behaviors such as systems thinking, adapting, problem-finding, creative problem-solving, visualizing, and improving, collaboration and communication. As the above-mentioned terminology would not be part of the children's everyday language, this may be a reason why they mentioned content rather than attitudes and habits of mind when asked about what they learned during the project.

Inclusive Science, Technology, Engineering, Arts, and Mathematics Education: Transdisciplinary Science, Technology, Engineering, Arts, and Mathematics Education Needs to Cater for All Abilities in the Classroom Through a Spiral and Scaffolding Approach to Teaching and Learning

Even though all stakeholders, children and teachers were enthusiastic about STEAM education and participating in this project, it was important to understand the challenges and perspectives of those experiencing and those tasked with implementing STEAM instruction. From the outset, a challenge in this project was to ensure that *"entertaining and educational demonstrations on interactive* technologies" (Artist) were developed. Ireland's Digital Skills Strategy 2015–2020 (DES, 2015) highlighted the need for all stakeholders to work together to support the integration of technology in every classroom in a systematic and focused way. The weather station was therefore designed by the contemporary artist in consultation with the teachers and children in the pilot school and the STEAM education experts running the project, to "*realize the potential of digital technologies to enhance teaching, learning and assessment so that Ireland's young people become engaged thinkers, active learners, knowledge constructors and global citizens to participate fully in society and the economy*" (DES, 2015, p. 5).

The children were asked in their surveys what they found challenging when working with the live data from the weather station. Many of the children did not comment on this. Three out of the 20 children found working with data, captured by the weather station, "confusing" and "too detailed." When probed further during their focus groups, five out of the 20 children specifically mentioned they found developing the temperature tree difficult when "*predicting how many leaves we needed per hour," "matching and making decisions about the colors and temperatures."* One child mentioned that they found it difficult to construct the *"pictures"* but continued by saying *"I like it but hard."* These comments show how challenging data science can be for children in the elementary classroom and that a spiral approach to the use of the weather station was needed, whereby the children keep revisiting the data and on every

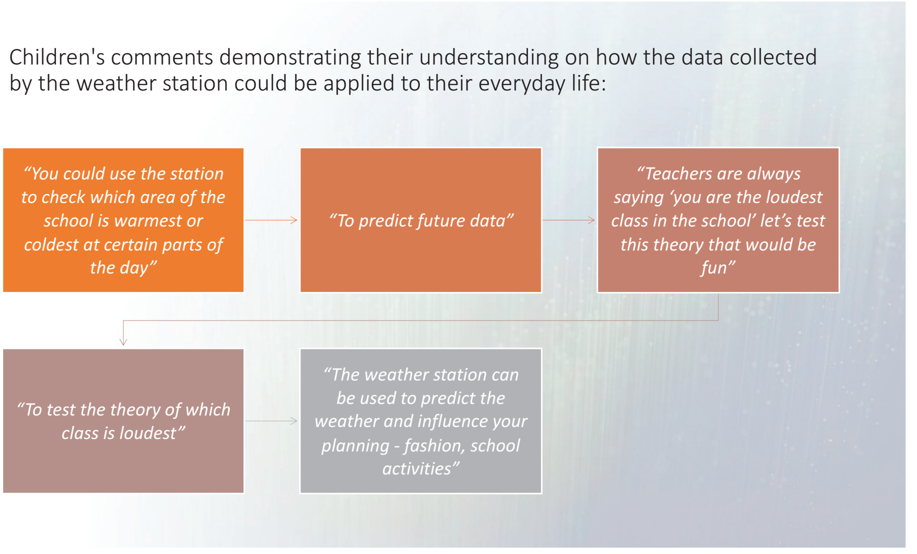


FIGURE 13 | Children's comments on how data collected from the weather station could be applied to everyday life.

revisit, they learn something new from the previous activity. The children were given time to explore and make sense of the different visual representations of the data on the website before applying the data to different activities and explorations. The teacher stated that *"Initially, I think they found the data overwhelming. They benefited massively from a session whereby we just talked through each of the graphs/pages on the sensor website and looked at how the data was being presented. It was evident that children really enjoyed the visual representation of data for example – the temperature heat map. This is why we specifically chose this data to work with."* Even though some children found the STEAM lessons difficult they still enjoyed the lessons as they were based on the children's interests and were learning in context.

The teacher was probed about the challenges that children might face when incorporating the weather station into the elementary classroom and how she overcame this. She arranged children into mixed ability teams with a variety of different skills, which engaged and motivated students: "*The lessons were pitched to allow all learning styles to add something to the class. Children were paired together during the brainstorming sessions so that they could bounce ideas off one another. They recorded their answers, one person acting as a recorder and the other as a presenter. During the talk and discussion sessions, I used a variety of questioning strategies to keep the children engaged. The higher ability children enjoyed teasing out the open ended, higher order questions. Children were keen to showcase their own unique talents so we made a list of ways our skills could be adapted to suit the project at hand. We had every type of talent on offer – coders, designers, painters, presenters, scribes."* The researchers acknowledge the importance of how the teacher's awareness and ability to scaffold the learning to cater for all learners within the class contributed to the successful implementation of the project.

Attitudes to Data Science: Challenging Children's Attitudes and Perceptions Toward Data Science Requires a More Targeted Approach, Connecting Data to Their Everyday Lives

The children were asked would they like to be a data scientist when they were older. Nine children commented with a resoundingly negative response. Some of the children felt that "*it's hard,*" worrying that they "*won't be able*" and that it is "*a big job.*" Another felt that it would be "*boring and I won't enjoy it.*" The aim of the project was not to encourage children into careers in data science, however, their comments are interesting. From the teachers', STEAM education experts' and the artist's point of view, it was felt that the project had helped in dispelling the negative attitudes toward data science. This finding relates to our finding that a child did not "*see the purpose of the data*" and could not relate it to everyday life. These results show that in future STEAM activities involving the weather station that relates data to children's everyday lives needs to be specifically addressed.

Four out of the 20 children had an idea of what they wanted to be when they were older and it didn't involve data science. One child did comment however that "*I want to be an engineer, so I guess this is the same thing.*" This child could identify the links across the different disciplines after completing phase 4 of the STEAM project, which was a very positive result.

The children were then asked to describe the environment monitoring station in three words. As can be seen from **Figure 13**, the children even though they found the project interesting, creative and engaging, they also found it challenging and detailed. As can be seen from the size of the words in the word cloud, while the children found using data from the IoT based Environment Monitoring System "interactive," "interesting," "useful," and "informative" they equally found it "confusing." This "*odd*" but "*useful*" project forced them and teachers out of their comfort zones bringing this "*interactive*" "*different*" and "*informative*"

STEAM education experience to "*the next-level*" where the children could appreciate and acknowledge the importance of STEAM in the "*future*" (**Figure 13**). This project certainly challenged children and teachers while at all times supporting them in their journey into STEAM education using an IoT based Environment Monitoring System.

Professional Development: A Science, Technology, Engineering, Arts, and Mathematics Education Outreach Program Delivered by a Multi-Disciplinary Team Provides a Means of Professional Development for All Stakeholders Involved

The teacher stated that after taking part in this project she is "*more confident now*" in delivering STEAM activities using the weather station. The professional development session provided the teacher with *"a deeper knowledge of how the weather station could be used from an adult's perspective."* The artist also developed new STEAM skills: *"it made me discover new developments and technologies. For example, the ways of connecting physical conditions such as temperature to digital representations using sigfox and p5/tone.js. Technologies I was not aware of before."* This project had not only an impact on children's and teachers' STEAM skills, attitudes and confidence but also on the many other stakeholders involved in this project. The artist felt that *"the project gave me a better understanding of the development cycle. From analysis, design development and testing to complete the creation of a project, increasing confidence."*

The teacher felt that if educators can experience STEAM being delivered in the classroom that "*it gives you more confidence yourself to go off and adapt ideas to suit your own teaching style and your own class.*" She would like to see future professional development for teachers to include how to incorporate new and emerging technologies in the classroom. The teacher commented that "*I love seeing sample lessons being delivered or ideas for lessons fleshed out when I gather with other teachers in a collaborative session.*" The ongoing support delivered to teachers during the STEAM-Ed project, which was delivered within the school environment provided the teacher with greater confidence to integrate art and technology into her classroom. "*Continuous professional development and the fact that we were all learning together was the key to the success of integrating the weather station into the elementary classroom and its many possibilities*" (Expert in Visual Arts Education). The strong focus on the arts in the professional development sessions was very evident in the teacher's delivery of her STEAM lessons, where she did not treat the arts as an add-on to STEM education but delivered a truly transdisciplinary model to STEAM education. The Expert in STEM Education also stated that the professional development sessions with teachers and stakeholders were "*mutually beneficial, where I learned so much about the implementation and delivery of STEAM education on the ground in the classroom.*" The collaborative approach between educators and experts in the field strengthened the focus and knowledge content, sharing expertise and encouraging different ways to view an idea or concept. "*We as educators need to be always open to moving out of our comfort zone and like our students expose ourselves to new experiences and ideas. . .when initially got involved in STEAM Ed I was worried that I won't be able to contribute to STEM but as the project developed, I realized a lot of what we do in art is interconnected to STEM and one informs the other. Now I am all about STEAM"* (Expert in Visual Arts Education). Therefore, professional development for teachers, delivered by a wide variety of people from different professions and backgrounds, can result in transformative change in people's professional practices.

DISCUSSION

Across the educational community, there have been numerous debates questioning how can the arts be integrated into STEM in an authentic way? There are many challenges to the design and delivery of STEAM education, where educators struggle with a clear conceptualization of STEAM and how the disciplines might be connected (Ejiwale, 2013; Guyotte et al., 2015; Quigley and Herro, 2016; Quigley et al., 2017). This paper presented an approach to the delivery of a STEAM educational outreach program, involving the delivery of a transdisciplinary approach to STEAM education with the aim of addressing key challenges facing teachers at elementary level. The boundaries between the different subject areas were broken down, where technology, art, mathematics and engineering, took on a more prominent role in STEAM, while elementary children and teachers explored data science using an IoT based Environment Monitoring System (the IOT weather station). The transdisciplinary pedagogies implemented during this project allowed the children to learn through a blending of disciplines, in order to develop a deep level of understanding of concepts and skills from a variety of disciplines and how they are connected (Herro and Quigley, 2017). The approach taken involved the conceptualization of STEAM as pedagogically and mutually instrumental, where neither the STEM nor the arts are privileged over the other but are both treated equally (Mejias et al., 2021). It is important to note that the authors are not suggesting that STEAM education replaces or dilutes the teaching of specific disciplines within the education system but that it can be an important addition to a curriculum. We recognize the importance of learning and developing concepts and skills within specific subject areas, but we should make space in our curriculum to explore transdisciplinary practices.

The case study approach used during the study allowed the researchers to obtain valuable insights into teachers', scientists', and artists' perspectives, children's experiences and the role of innovative technology in STEAM education through the use of data science and an IoT based Environment Monitoring System. One finding of the research was that transdisciplinary STEAM Education needs to consider and cater for all abilities in the classroom through a spiral and scaffolding approach to the teaching and learning process in the elementary classroom. A spiral approach involves revisiting content, and every time content is revisited, the child gains deeper knowledge of the topic. The complexity of the topic or theme increases with each revisit and new learning has a relationship with old learning and is put in context with the old information (Bruner, 1960). Flexible child-centered approaches to STEAM education, as implemented in this project, provided an impactful and meaningful learning opportunity for children of all abilities (Mishra et al., 2012; Park et al., 2016). Below we discuss two primary ideas that were salient through our analysis: (1) innovative data capturing technologies in STEAM education and (2) collaborative approaches to the delivery of STEAM education.

Innovative Data Capturing Technologies in Science, Technology, Engineering, Arts, and Mathematics Education

The STEAM-ED project demonstrates how both physical and digital technologies (micro controllers, sensors, interactive software and web development tools) can provide fresh and novel ways to engage with teaching and learning practices in the elementary classroom. The project brought the idea of the traditional weather station, which generally requires children to capture data on rainfall, temperature and wind speed manually, to a whole new level using sensor technologies and the IoT. This research found that an IoT based Environment Monitoring System can provide a wide variety of STEAM teaching and learning opportunities and can positively impact children's and teachers' knowledge and skills in STEAM. The STEAM activities delivered to the children involved the four C's: communication, collaboration, critical thinking and creativity, all of which have been recognized as essential skills for the 21st century learner (Partnership for 21st century, 2011). The activities were developed with the aim of unlocking children's creative thinking skills and technical innovation (Robelen, 2011). The approach taken involved teachers and children developing STEAM knowledge, skills and practices, through experiences shaped by imagination and creativity. Creativity is an essential component of innovation and arts education is the key to creativity.

The project focused on the "transformation of experience" (Kolb, 1984), engaging children in STEAM by involving them in exciting, inquiry-based real-time data acquisition and computational modeling, showcasing transdisciplinary practices, merging creative subjects such as art and music with STEM subject disciplines. The IoT weather station looked at re-conceptualizing the mathematics classroom as a place where students learn mathematics by exploring the uses of mathematics across all of the subjects in STEAM education (Coffland and Xie, 2015). The teacher made data science intriguing, game-based, and fun for the children. She brought the data alive in the classroom by developing the children's curiosity, aesthetic understanding, and expression during the STEAM activities through art and creativity (Bu and Hohenwarter, 2015). Rather than spending a significant amount of time calculating and gathering and recording data sets, the children spent their time during lessons engaged in higher-order thinking, offering children and teachers different and original ways to analyze, reason and communicate information and data. For example, exploring different ways of representing data and using data to develop games and animations (Leavy and Hourigan, 2015, 2016). Therefore, the technology used in this project supported STEAM pedagogy by creating visual representations of data and enabling personalized learning (Grant, 2015). A variety of innovative pedagogies were used while analyzing, visualizing and presenting data, for example, designing a temperature tree, coding computer games, making line art, using graphs for inspiration, and composing music. These activities using technology allowed children to experience the aesthetic dimension of data in mathematics, bringing mathematics to life through STEAM education. The creative approach also gave children agency, as they reimagined the data and devised their own way to communicate the data to make it more visual and relevant to them. This model of integrating the IoT into STEAM education allowed the children to be creative and use their imaginations, allowing them to envisage data science in a different way (Sousa and Pilecki, 2013).

Collaborative Approaches to the Delivery of Science, Technology, Engineering, Arts, and Mathematics Education

The main feature of this project was to develop awareness of the synergy between visual art and STEM. An important element of this was to look outwards toward the contemporary world of art as well as to industry. The approach involved a network of stakeholders, including experts in STEM and visual arts education with artists, architects, scientists, pre-service and in-service teachers and children in a pilot school. The values of collaboration and inclusivity were central to the STEAM-ED project, as the project attempted to break down disciplinary boundaries and see the potential of merging STEM and visual art through transdisciplinary processes, skills and concepts. The study set out to review and adapt teaching practices by looking to the creative industry to develop a transdisciplinary educational environment. Against this background, this study is important because it helps us understand how authentic learning occurs in STEAM. From the conception phases to the completion of the study, the researchers were informed by a wide variety of stakeholders with teachers and children at the center of this collaboration A collaborative approach gave a clear picture of what STEAM is and what it is intended to accomplish (Colucci-Gray et al., 2017; Katz-Buonincontro, 2018).

This educational outreach project provided a means of teacher professional development on innovative, and creative STEAM pedagogies. Throughout all phases of this project, a strong focus was placed on professional development in context and through a variety of different means. This element of the project was important as there is considerable divergence among educators on their ideas around what STEAM is and how it is delivered (Colucci-Gray et al., 2017, 2019; Conner et al., 2017). A highly successful element of this project involved teachers in the pilot school, working together in developing STEAM activities appropriate for their elementary classrooms.

A cooperative approach was found to be a resourceful way to implement professional development. This acted as a means of "learning as you teach" moving the teachers from their comfort zones to their learning zones as they responded to alternative and creative approaches to technologies and STEAM pedagogies. This allowed more opportunities for action and reflection and to develop the teacher's confidence in developing their own ideas for teaching and promoting STEAM (Jarvis and Pell, 2004; Varley et al., 2008). The support structures provided to the teachers (professional development, feedback, mentoring) were established and maintained throughout the STEAM Ed project. The fact that the support structures were delivered within the school working environment developed the teacher's confidence in integrating art and technology into their classrooms in a meaningful and authentic way (Goktas et al., 2013). The strong focus on the arts in the professional development sessions was evident in the teacher's delivery of her STEAM lessons, where she did not treat the arts as an add-on to STEM education but delivered a truly transdisciplinary model to STEAM education (Quigley et al., 2017). One key finding from this research is that there is a need for high-quality professional development of pre-service and in-service teachers learning the context of how to effectively incorporate transdisciplinary STEAM lessons and activities into their teaching (Herro and Quigley, 2017). Teaching transdisciplinary material requires unique skillsets and a way of thinking that traditionally, professional development programs, may not emphasize. At all times we ensured that the delivery of STEAM in the pilot school veered away from being one-sided to being more mutually beneficial and pedagogical (Mejias et al., 2021). It was also found that this STEAM education outreach program delivered by a multi-disciplinary researcher/practitioner partnership provided a means of professional development not only for teachers but for all stakeholders involved. Knowledge integration is an inherent aspect of artistic inquiry, as practice emerges from observation and perception of the world around us. In recent times, the STEAM model has undergone a rebirth and gained momentum, widely adapted across all sectors. Involving the artistic and STEM communities in the design and delivery of STEAM presents a resourceful argument for the design of a STEAM curriculum.

CONCLUSION

Today's world can be characterized by a new explosion of scientific knowledge and a growing array of complex societal problems. It is appropriate that curricula should continue to evolve, and digital technologies will need to be an integral part of this evolution, perhaps by embedding flexible approaches that develop interactive, collaborative and inquiry-based learning environments that are relevant, challenging and inclusive. Future planning in STEAM education needs to truly interrogate what a transdisciplinary approach to STEAM education looks like and how this can be achieved. As can be seen from this project integrating STEAM into an education system requires time, collaboration among a wide variety of stakeholders, on-going support, intensive high-quality professional development, resources and of course buy-in from educators and school communities. STEAM education is not a new concept, however, the exploration of technology to promote 21st century skills in the STEAM classroom has not been researched in any great depth. Further research is needed on the potential of technology to support the development of STEAM competencies and attitudes. It is important to note that the STEAM-ED project did not set out to promote careers or to develop future scientists, engineers or data scientists etc. It achieved what it set out to i.e., develop a shared awareness and understanding of STEAM education across teacher educators, teachers and individuals from the STEM and creative industry, and to inform best practices in STEAM education. The teachers, children and all stakeholders involved in the project developed a sense of awareness of the interconnectivity between all the different STEAM disciplines and beyond. It also highlighted the importance of art and the integration of art in school curricula. This paper has provided valuable insights into teachers', scientists', and artists' perspectives, children's experiences and the role of innovative technology in STEAM education.

The success of the STEAM-ED project can be attributed to the collaboration between various stakeholders in the design and implementation of the project (artists, architects, scientists, STEAM education experts, teachers, and students). We must also acknowledge that undertaking a multifaceted project successfully can be difficult. Following a few basic principles can make a real difference to the success of the implementation of a STEAM education project. From the initial stages of the project, the researchers had a strong vision and a sense of what they wanted from the project. Yet, we could not have predicted the direction and the specific outputs due to the organic nature of the project and the expertise of the artists involved. People make ideas happen. The STEAM team was inclusive in the sense that the researchers realized from the beginning, that for STEAM to be truly authentic then it needed to be informed by different perspectives and experiences. Within the team there were creators, makers, thinkers, developers, and implementers as well as the engagers. It was found that during the STEAM-ED project when seeking authentic creative STEAM experiences, all stakeholders in the process needed to have an openness to change, moving out of their comfort zone and being confronted with the unknown. Therefore, when incorporating art into STEAM the integrated process needs to be inclusive, open-ended, flexible, and adaptable. A project without different views would have been a very solitary activity. Therefore, when engaging with such an initiative people will need to consider who they will need to make their project happen, as well as allowing flexibility and a mindset that is open to change and adaptability. Choose your collaborative partners wisely and establish a set of collaborative guidelines that reflect the project's aims. It is important to mention that the project design was framed around not only the expertise of the stakeholders involved but also around the unique conditions of the environment within the specific pilot school in which it was realized. The successes and the limitations shaped the direction of the project which included expertise, experiences and knowledge of the STEAM team, professionalism of the teachers involved as well as school environment and the limitations of COVID-19.

What remains important during a collaborative educational project is the vision. A shared vision among all stakeholders provides a sense of cohesion and a united purpose. This vision should be specific, motivational and achievable. Projects in STEAM will be ever evolving and fluid, with many possible outputs that will be informed by the expertise, knowledge and experiences of all the stakeholders involved.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Mary Immaculate College Ethics Committee. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin. Written informed consent was obtained from the participating adults (over the age of 18) and from the minors' legal guardians/next of kin for the publication of any potentially identifiable images or data included in this article.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct, and intellectual contribution to the work, and approved it for publication.

FUNDING

This project was funded by Science Foundation Ireland under their Discover Funding Program (project ID:17/DP/5257).

ACKNOWLEDGMENTS

Thank you to all the teachers and children and the Principal of the pilot school where this project was carried out.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/feduc.2022.757866/full#supplementary-material

REFERENCES

Adams, J. (2014). Finding time to make mistakes. *Int. J. Art Design Educ.* 33, 2–5. doi: 10.1111/j.1476-8070.2014.12040.x

Augustine, N. R., Barrett, C., Cassell, G., Grasmick, N., Holliday, C. Jr., Jackson, S. A., et al. (2010). *Rising above the Gathering Storm, Revisited: Rapidly Approaching Category 5*. Washington, DC: National Academies Press.

Baig, M. I., Shuib, L., and Yadegaridehkordi, E. (2020). Big data in education: a state of the art, limitations, and future research directions. *Int. J. Educ. Technol. High. Educ.* 17:44. doi: 10.1186/s41239-020-00223

Bakker, A., and Derry, J. (2011). Lessons from inferentialism for statistics education. *Math. Think. Learn.* 13, 5–26.

Bequette, J. W., and Bequette, M. B. (2012). A place for art and design education in the STEM conversation. *Art Educ.* 65, 40–47.

Blatt-Gross, C. (2013). Toward meaningful education: investigating artful behavior as a human proclivity in the classroom. *Int. J. Educ. Arts* 14, 1–22.

Braun, V., and Clarke, V. (2006). Using thematic analysis in psychology. *Qual. Res. Psychol.* 3, 77–101.

Bruner, J. (1960). *The Process of Education*. Cambridge, MA: Harvard University Press.

Bryan, L., Moore, T. J., Johnson, C. C., and Roehrig, G. (2016). "STEM road map – a framework for integrated STEM education," in *Integrated STEM Education*, eds C. C. Johnson, E. E. Peters-Burton, and T. J. Moore (New York, NY: Routledge), 23–34.

Bu, L., and Hohenwarter, M. (2015). "Modelling for dynamic mathematics," in *Emerging Technologies for STEAM Education. Educational Communications and Technology: Issues and Innovations*, eds X. Ge, D. Ifenthaler, and J. Spector (Cham: Springer), 355–379.

Burnard, P., Colucci-Gray, L., and Sinha, P. (2021). Transdisciplinarity: letting arts and science teach together. *Curric. Perspect.* 41, 113–118. doi: 10.1007/s41297-020-00128-y

Cobb, G. W., and Moore, D. S. (1997). Mathematics, statistics, and teaching. *Am. Math. Mon.* 104, 801–823.

Coffland, D., and Xie, Y. (2015). "The 21st century mathematics curriculum: a technology enhanced experience," in *Emerging Technologies for STEAM Education. Educational Communications and Technology: Issues and Innovations*, eds X. Ge, D. Ifenthaler, and J. Spector (Cham: Springer), 311–330.

Cohen, L., Manion, L., and Morrison, K. (2000). *Research Methods in Education*, 5th Edn. London: Routledge Falmer.

Colucci-Gray, L., Burnard, P., Cooke, C., Davies, R., Trowsdale, J., and Gray, D. (2017). Reviewing the potential and challenges of developing STEAM education through creative pedagogies for 21st learning: How can school curricula be broadened towards a more responsive, dynamic, and inclusive form of education? *Br. Educ. Res. Assoc.* doi: 10.13140/RG.2.2.22452.76161

Colucci-Gray, L., Burnard, P., Gray, D., and Cooke, C. (2019). "A critical review of STEAM (science, technology, engineering, arts, and mathematics)," in *Oxford Research Encyclopedia of Education*, ed. P. Thomson (Oxford: Oxford University Press), 1–26.

Conner, L. D. C., Tzou, C., Tsurusaki, B. K., Guthrie, M., Pompea, S., and Teal-Sullivan, P. (2017). Designing STEAM for broad participation in science. *Creat. Educ.* 8, 2222–2231. doi: 10.3390/molecules26237121

Connor, A. M., Karmokar, S., and Whittington, C. (2015). From STEM to STEAM: strategies for enhancing engineering & technology education. *Int. J. Eng. Pedag.* 5, 37–47. doi: 10.1038/srep16327

Costa, A. L., and Kallick, B. (2008). *Learning and Leading with Habits of Mind:16 Essential Characteristics of Success*. Alexandria, VA: ASCD.

Creswell, J. W. (2014). *Research Design. Qualitative, Quantitative and Mixed Methods Approaches*, 4th Edn. Thousand Oaks, CA: Sage Publications.

Crossick, G., and Kaszynska, P. (2016). *Understanding the Value of Arts & Culture. The AHRC Cultural Value Project*. Swindon: Arts & Humanities Research Council.

Davis, T. (2017). The Internet of Things for Kids. In the "Talking Window Garden" project, students create "smart" plant pots that use sensors to collect and analyze data on the health of their plants. *Sci. Child.* 54, 84–91.

DES (2015). *Ireland's Digital Skills Strategy 2015-2020: Enhancing Teaching, Learning and Assessment' [Report]*. Dublin: Department of Education and Skills.

Doorley, R. (2014). *Thinkerlab. A Hands-on Guide for Little Thinkers*. Boston: Roost Books.

Eisenhardt, K. M. (1989). Building theories from case study research. *Acad. Manage. Rev.* 14, 532–550. doi: 10.1258/0951484021912851

Ejiwale, J. (2013). Barriers to successful implementation of STEM education. *J. Educ. Learn.* 7, 63–74.

European Commission (2007). *Science Education Now: A Renewed Pedagogy For The Future Of Europe*. Brussels: European Commission Directorate.

Franklin, C., Kader, G., Mewborn, D., Moreno, J., Peck, R., Perry, M., et al. (2007). *Guidelines and Assessment for Instruction in Statistics Education (GAISE) Report: A Pre-K-12 Curriculum Framework*. Alexandria, VA: American Statistical Association.

Gerlach, J. (2012). *STEM: Defying a Simple Definition*. Washington: NSTA Reports.

Getzels, J. W., and Jackson, P. W. (1962). *Creativity and Intelligence: Explorations with Gifted Students*. Hoboken, NJ: Wiley.

Geum, Y., and Bae, S. (2012). The recognition and needs of elementary school teachers about STEAM education. *J. Korean Inst. Indus. Educ.* 37, 57–75.

Goktas, Y., Gedik, N., and Baydas, O. (2013). Enablers and barriers to the use of ICT inprimary schools in Turkey: a comparative study of 2005-2011. *Comput. Educ.* 68, 211–222.

Gomes, D., and McAuley, V. (2013). *Science Outreach and Science Education; The Analysis of Dilemmas Faced to Promote the Creation of the Third Space*. Ireland: National University Ireland.

Grant, M. M. (2015). "Using mobile devices to support formal, informal and semi-formal learning," in *Emerging Technologies for STEAM Education. Educational Communications and Technology: Issues and Innovations*, eds X. Ge, D. Ifenthaler, and J. Spector (Cham: Springer), 157–177.

Gregory, G. H., and Kuzmich, L. (2005). *Differentiated Literacy Strategies for Student Growth and Achievement in Grades K-6*. Thousand Oaks, CA: Corwin press.

Guyotte, K. W., Sochacka, N. W., Costantino, T. E., Kellam, N., Kellam, N. N., and Walther, J. (2015). Collaborative creativity in STEAM: narratives of art education students' experiences in transdisciplinary spaces. *Int. J. Educ. Arts* 16, 1–35.

Henriksen, D. (2014). Full STEAM ahead: creativity in excellent STEM teaching practices. *STEAM J.* 1:15.

Henriksen, E. K., Jensen, F., and Sjaastad, J. (2015). The role of out-of-school experiences and targeted recruitment efforts in Norwegian science and technology Students' educational choice. *Int. J. Sci. Educ. Part B* 5, 203–222.

Herro, D., and Quigley, C. (2017). Exploring teachers' perceptions of STEAM teaching through professional development: implications for teacher educators. *Prof. Dev. Educ.* 43, 416–438.

Hiebert, J., and Lefevre, P. (1986). "Conceptual and procedural knowledge in mathematics: an introductory analysis," in *Conceptual and procedural knowledge: The Case of Mathematics*, ed. J. Hiebert (Hillsdale, NJ: Lawrence Erlbaum Associates), 1–27. doi: 10.1348/000709910X513933

Honey, M., Pearson, G., and Schweingruber, H. A. (2014). *STEM Integration in K-12 Education: Status, Prospects, and an Agenda for Research*. Washington, DC: National Academies Press.

Hotchkiss, R., and Dickerson, D. (2008). A remote-sensing science mission. *Sci. Child.* 2008, 44–49.

ITEEA (2020). *Standards for Technological and Engineering Literacy: Defining the Role of Technology and Engineering in STEM Education (STEL)*. Reston, VI: ITEEA.

Jarvis, T., and Pell, A. (2004). Primary teachers' changing attitudes and cognition during a two year science in-service programme and their effect on pupils. *Int. J. Sci. Educ.* 26, 1787–1811.

Jose, S., Patrick, P. G., and Moseley, C. (2017). Experiential learning theory: the importance of outdoor classrooms in environmental education. *Int. J. Sci. Educ. Part B* 7, 269–284.

Katz-Buonincontro, J. (2018). Gathering STE(A)M: policy, curricular, and programmatic developments in arts-based science, technology, engineering, and mathematics education Arts Educ. *Policy Rev.* 119, 73–76.

Kolb, D. A. (1984). *Experiential Learning: Experience as the Source of Learning and Development*. Hoboken, NJ: Prentice-Hall.

Kreuger, R. (2009). *Focus Groups: a Practical Guide for Applied Research*, 4th Edn. London: Sage Publications.

Kvale, S. (1996). *InterViews: An Introduction to Qualitative Research Interviewing*. Thousand Oaks, CA: Sage Publications.

Land, M. H. (2013). Full STEAM ahead: the benefits of integrating the arts into STEM. *Proc. Comput. Sci.* 20, 547–552. doi: 10.1016/j.procs.2013.09.31

Leavy, A. (2020). *Data and Chance in the senior primary classes. Commissioned Research Paper*. Dublin: NCCA.

Leavy, A., and Hourigan, M. (2015). Motivating inquiry in statistics and probability in the primary classroom. *Teach. Stat.* 37, 41–47. doi: 10.1111/test.12062

Leavy, A., and Hourigan, M. (2016). Crime Scenes and Mystery Players! Using interesting contexts and driving questions to support the development of statistical literacy. *Teach. Stat.* 38, 29–35.

Lee, M.-S. (2014). The effect of teachers' training and teaching experience for integrative education on teacher's concerns regarding STEAM. *Korean J. Educ. Res.* 52, 251–271.

Lucas, B. (2016). A five-dimensional model of creativity and its assessment in schools. *Appl. Meas. Educ.* 29, 278–290. doi: 10.1080/08957347.2016.1209206

MacDonald, J. (2003). Assessing online collaborative learning: process and product. *Int. J. Comput. Educ.* 40, 377–391.

Martinez, S. L., and Stager, G. S. (2013). *Invent to Learn: Making, Tinkering, and Engineering in the Classroom*. Torrance, CA: Constructing Modern Knowledge Press.

Martinez, W., and LaLonde, D. (2020). Data science for everyone starts in kindergarten: strategies and initiatives from the American Statistical Association. *Harv. Data Sci. Rev.* 2. doi: 10.1162/99608f92.7a9f2f4d

Maslyk, J. (2016). *STEAM Makers: Fostering Creativity and Innovation in the Elementary Classroom: U.S.* Thousand Oaks, CA: Corwin press.

Mejias, S., Thompson, N., Sedas, R. M., Rosin, M., Soep, E., Peppler, K., et al. (2021). The trouble with STEAM and why we use it anyway. *Sci. Educ.* 105, 209–231. doi: 10.1002/sce.21605

Merriam, S. (1998). *Qualitative Research and Case Study Applications in Education. Revised and Expanded from "Case Study Research in Education"*. San Francisco, CA: Jossey-Bass.

Merriam, S. (2009). *Qualitative Research: A Guide to Design and Implementation*. San Francisco, CA: Jossey-Bass.

Mishra, P., Henriksen, D., and The Deep-Play Research Group. (2012). On being (in)disciplined. *Tech Trends* 56, 18–21.

Monkeviciene, O., Autukeviciene, B., Kaminskiene, L., and Monkevicius, J. (2020). Impact of innovative STEAM education practices on teacher professional development and 3-6 year old children's competence development. *J. Soc. Stud. Educ. Res.* 11, 1–27.

Moore, T. J., and Smith, K. A. (2014). Advancing the state of the art of STEM integration. *J. STEM Educ.* 15, 5–10.

Morgan, D. L. (1988). *Focus Groups as Qualitative Research*. Newbury Park, CA: Sage Publications.

Morrin, A. M., and Liston, M. (2020). Engaging children with authentic STEAM learning experiences through design-based approaches. *Connect. Sci. Learn.* 2:202.

OECD (2016). *Innovating Education and Educating for Innovation: The Power of Digital Technologies and Skills*. Paris: OECD Publishing. doi: 10.1787/9789264265097-en

Park, H., Byun, S., Sim, J., Han, H.-S., and Baek, Y. S. (2016). Teachers' perceptions and practices of STEAM education in South Korea. *EURASIA J. Math. Sci. Technol. Educ.* 12, 1739–1753.

Patton, M. Q. (2002). *Qualitative Research and Evaluation Methods*, 3rd Edn. Thousand Oaks, CA: Sage Publications.

Perkins, D. (1995). *Outsmarting IQ: The Emerging Science of Learnable Intelligence*. New York, NY: Free Press.

Piro, J. (2010). Going from STEM to STEAM: the arts have a role in America's future, too. *Educ. Week* 29, 28–29.

Putnam, R. T., and Borko, H. (2000). What do new views of knowledge and thinking have to say about research on teacher learning? *Educ. Res.* 29, 4–15.

Quigley, C. F., and Herro, D. (2016). Finding the joy in the unknown: implementation of STEAM teaching practices in middle school science and math classrooms. *J. Sci. Educ. Technol.* 25, 410–426.

Quigley, C. F., Herro, D., and Jamil, F. M. (2017). Developing a conceptual model of STEAM teaching practices. *Sch. Sci.* 117, 1–12.

Quigley, C. F., Herro, D., King, E., and Plank, H. (2020). STEAM designed and enacted: understanding the process of design and implementation of STEAM curriculum in an elementary school. *J. Sci. Educ. Technol.* 29, 499–518.

Rennie, L., Venville, G., and Wallace, J. (2012). "Reflecting on curriculum integration: seeking balance and connection through a worldly perspective," in *Integrating Science, Technology, Engineering, and Mathematics: Issues, Reflections, and Ways Forward*, eds L. Rennie, G. Venville, and J. Wallace (New York, NY: Routledge), 123–142.

Robelen, E. W. (2011). Building STEAM: blending the arts with STEM subjects. *Educ. Week* 31:8.

Russell, A. W., Wickson, F., and Carew, A. (2008). Transdisciplinarity: context, contradictions and capacity. *Sci. Direct Fut.* 40, 460–472.

Saldaña, J. (2021). *The Coding Manual for Qualitative Researchers*. Newbury Park, CA: SAGE Publications Limited.

Shanken, E. A. (2002). Art in the information age: technology and conceptual art. *Leonardo* 35, 433–438.

Sharapan, H. (2012). From STEM to STEAM: how early childhood educators can apply fred rogers' approach. *YC Young Child.* 67, 36–40.

Shin, J. H. (2013). Survey of primary & secondary school teachers' recognition about STEAM convergence education. *Korean J. Learn. Sci.* 7, 29–53.

Silverstein, L. B., and Layne, S. (2010). "What is arts integration?," in *Arts Integration Schools: What, Why, and How*, eds L. Silverstein, A. Duma, and S. Layne (Washington, DC: The John F. Kennedy Center for the Performing Arts), 1–7.

Sousa, D. A., and Pilecki, T. (2013). *From STEAM to STEAM: Using brain-Compatible Strategies to Integrate the Arts*. Thousand Oaks, CA: Corwin.

Stark, L., and Crawford, K. (2019). The work of art in the age of artificial intelligence: what artists can teach us about the ethics of data practice. *Surveill. Soc.* 17, 442–455.

Sternberg, R. (1996). *Successful Intelligence: How Practical and Creative Intelligence Determine Success in Life*. New York, NY: Simon and Schuster.

Stocklmayer, S. M., Rennie, L. J., and Gilbert, J. K. (2010). The roles of the formal and informal sectors in the provision of effective science education. *Stud. Sci. Educ.* 46, 1–44.

Tashakkori, A., and Teddlie, C. (2003). "The past and future of mixed methods research: from data triangulation to mixed model designs," in *Handbook of Mixed ethods in Social and Behavioral Research*, eds A. Tashakkori and C. Teddlie (Thousand Oaks, CA: Sage Publications).

Thompson, C. J., Barber, K., and Bourget, E. M. (2018). STEAM (Science, Technology, Engineering, Art, and Mathematics) education and teachers' pedagogical discontentment levels. *People Int. J. Soc. Sci.* 4, 496–518.

Varley, J., Murphy, C., and Veale, O. (2008). *Science in Primary Schools, Phase 1, Final Report*. Dublin: National Council for Curriculum and Assessment NCCA.

Wagner, T. (2012). *Creating Innovators: The Making of Young People Who will Change the World*. New York, NY: Simon and Schuster.

Wagner, T., and Dintersmith, T. (2015). *Most Likely to Succeed: Preparing our Kids for the Innovation Era*. New York, NY: Simon and Schuster.

Wilkerson, S., and Haden, C. M. (2014). Effective practices for evaluating STEM out-of-school time programs. *Aftersch. Matt.* 10–19. Available online at: https://files.eric.ed.gov/fulltext/EJ1021960.pdf

World Economic Forum (2020). *The Future of Jobs Report 2020*. Switzerland: World Economic Forum.

Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's Note: All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

Copyright © 2022 Liston, Morrin, Furlong and Griffin. This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY). The use, distribution or reproduction in other forums is permitted, provided the original author(s) and the copyright owner(s) are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.