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# Learning from the past; thinking for the future: reflections on STEM and its integration in formal and informal settings

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## Abstract

We discuss opportunities to integrate STEM across both formal and informal settings. Our reflections begin with looking back to *Making Science Matter: Collaborations Between Informal Science Education Organizations and Schools*, an influential report published by the Center for Advancement of Informal Science Education (CAISE) in 2010. We expand the arguments in that report to address integrating STEM education in formal and informal education particularly in the light of the growth of interest in teaching about 'wicked problems'. We discuss several issues that we believe need to be taken into account in developing closer formal/informal collaboration, and trace how they have emerged since the term STEM was first used in the 1960s. We conclude that a significant challenge, that is often overlooked, is that the term STEM has several different meanings and that institutions in formal and informal settings may have different outcomes in mind when collaborating with each other. The implications are that discussing the meaning and purpose of STEM are an essential first step in any collaboration between formal and informal institutions.

**Keywords** STEM, Integration, Formal and informal STEM education

In this paper, we discuss opportunities to integrate STEM across formal and informal settings. By 'formal settings' we mean schools and other primarily curriculum and/or qualification-focused institutions; by 'informal settings' we mean museums, science centres, botanic gardens, aquariums, etc., which also offer high quality educational experiences but are less constrained by assessment or curriculum factors. There is some overlap between the two types of setting for example, in planning their offer, museum educators often need to be sensitive to the school curriculum but we use the terms because they will be understood by most readers. Meanings of STEM

vary, as we will point out. In general, we are referring to science, technology, engineering and mathematics, as studied in school and/or as experienced in business and industry.

## Early arguments for collaborations between Informal Science Education Organizations and Schools

Our reflections begin with looking back to an initiative that one of us (JD) was involved with over 15 years ago. *Making Science Matter: Collaborations Between Informal Science Education Organizations and Schools* was published by the Center for Advancement of Informal Science Education (CAISE) in 2010 (Bevan et al., 2010). The report emerged from the work of the CAISE Formal/Informal Inquiry Group. The group, which began its work in 2008, explored the relationships between science education in formal and informal settings. Many of

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the report's findings are relevant to today's discussions of STEM education.

The report challenged the existing orthodoxy that education in informal settings was somehow secondary or supplementary to that offered by schools. The report's authors argued for "the hybrid nature of formal-informal collaborations" (p. 11). Working from theoretical perspectives and case studies, they argued that "in fact, formal [and] informal collaborations fall exactly within the core activities of both schools and informal learning organizations, including museums, youth programs, and libraries" (p. 11). By taking advantage of "the particular affordances and strengths of different institutional types," (p. 11) formal-informal collaborations could "meet shared goals of making science learning more accessible and compelling to young people in our communities" (p. 11). While this might be perceived as a somewhat optimistic position, there were sufficient examples, primarily from the US, but also from other countries, to substantiate the claim.

### **Towards collaborations between informal science education organisations and schools**

In this section, we expand the arguments used for integrating science across the formal/informal divide to look at integrating STEM education. We do this particularly in the light of the growth of interest in teaching about 'wicked problems' and realigning STEM education to meet the needs of all students not just those who might go on to study STEM subjects (Achiam et al., 2021).

Why is this an important issue? Part of the reason is that the challenges facing STEM education have never been greater. The proliferation of disinformation and misinformation has already had substantial negative impacts on society (Osborne & Pimentel, 2023). For example, substantial numbers of people at the height of the COVID-19 pandemic died because they refused to believe that vaccines were safe and trust in medical science decreased within some sectors of the public (Pew Research Center, 2022). Indeed, the global nature of the anti-science movement led some commentators to argue that science education had failed (Dillon & Avraamidou, 2020), because it lacked relevance to the multidisciplinary world experienced by learners. Informal science institutions, which are trusted by a high proportion of the public, have and will play a role in helping them to appreciate how STEM and those who are employed in associated industries work (Domenici, 2022). Collaborations between the formal and informal sectors can provide much-needed synergy that reinforces key messages and many informal institutions have greater access to STEM professionals and to up-to-date research than do schools (Alexandre et al., 2022). Recent events in the US only

amplify the urgent need for supporting STEM education however we can.

Another reason, hinted at above, for reflecting on integrating STEM education in formal and informal education, is that understanding and addressing wicked problems requires inter-, multi- and transdisciplinary approaches (Pohl et al., 2017). However, schools, particularly high schools, tend not to have adopted cross-subject approaches as their *modus operandi* (Wong & Dillon, 2019) (although there are some fabulous examples in the Odyssey schools in the US and the XP East academy in the UK).

There are several reasons for this lack of integration including the pressures of high stakes testing and the traditional organisation of the curriculum into separate subjects (Manuel, 2010). Informal institutions have more freedom to reflect the interdisciplinary nature of subjects, such as climate change, biodiversity loss and food security. Visitors to exhibitions and programmes at museums and science centres are more likely to see connections being made across subject boundaries than they are in school (Achiam et al., 2021). There is much in the out-of-school sector to inspire teachers and school leaders.

At this point, however, it is important to recognise that we are not starting from a situation in which there is no formal/informal STEM contact, indeed the scope of the collaborations is impressive. Almost 20 years ago, Phillips et al. (2007) found that more than 70% of US science museums, etc., had school-focused programmes:

*These programs include supplementary classroom experiences; integrated core academic curricula; student science learning communities located in afterschool, summer, and weekend programs; teacher professional development programs and communities; and even district infrastructure efforts around issues such as standards and assessment development or teacher preparation. (Bevan et al., 2010, p. 11).*

Research shows that these programmes have "been shown to spark curiosity, generate questions, and lead to a depth of understanding and commitment in ways that are often less possible when the same material is encountered in books or on screens" (p. 11).

Bevan et al. (2010), however, noted a major problem: "despite scores of such examples, these collaborations have generally failed to institutionalize: in many communities they come and go with changes in funding or leadership" (p. 11). They identified a number of reasons for the failure including a lack of funding for hybrid formal/informal collaborations, a lack of appropriate tools to assess and evaluate the outcomes of these novel

approaches and shifts in informal institutional priorities leading to cutting back on educational programmes. The report argued that it was important to move beyond these challenges by showing that these hybrid collaborations “fall *exactly within the core activities* of both schools and informal learning organizations, including museums, youth programs, and libraries” (p. 11, emphasis in original). The way forward, Bevan et al. argued, was “for more intentional and strategic deployments of resources, leading to collaborations that build on the particular affordances and strengths of different institutional types to meet shared goals” (p. 11).

The report outlined three “crucial understandings” that relate to the value and importance of these hybrid collaborations:

1. Scientific literacy is more than factual recall; it involves a rich array of conceptual understanding, ways of thinking, capacities to use scientific knowledge for personal and social purposes, and an understanding of the meaning and relevance of science to everyday life ...
2. Learning, and the development of a sustained commitment to a discipline, develops over multiple settings and timeframes...
3. Science education, as it is traditionally constituted, fails to engage and include a significant portion of society; most notably, women and people from high-poverty and non-dominant communities are under-represented in science professional, academic, and organized leisure-time activities ...

(Bevan et al., 2010, p. 12).

Fifteen years later, we argue that these three understandings are core to the future of any form of STEM education and point towards a similar need for “more intentional and strategic deployments of resources” that would facilitate collaborations. However, simply assuming that the same arguments will apply to fostering STEM collaborations across schools and informal organisations misses the issues and complexity inherent in STEM itself.

At this point, we are going to take a step back and look even further into history than 2010 to explain how we have got to where we are now and to set the scene for a discussion of what the future of STEM collaborations might hold.

### **STEM: its history and evolution—lessons from the past**

In this section, we take a look at what the history of STEM as a policy driver and educational movement can tell us that may help to frame the search for future orientations. We also identify a challenge, that is often

overlooked, which is that STEM has a number of different meanings and that institutions in formal and informal settings may have different outcomes in mind when collaborating with each other. We see this discussion as significant, not just because it identifies the issue, but that it also suggests what might be done to ensure that collaborations have a greater chance of success than might otherwise be the case.

One aspect of the issue is illustrated by a quote from a recent paper in a science education journal: “The term “STEM” originated in 2001 from Judith Ramaley, the director of the U.S. National Science Foundation’s Education and Human Resources division...” (Roehrig & Karışan, 2022, p. 1). Surprisingly, perhaps, the origin of the term STEM is opaque, with conflicting accounts given by multiple authors. Despite claims for being a relatively recent invention, it has been in use since *at least* 1964. We do acknowledge, however, that its use has taken off in the last twenty-plus years, because it has become a key driver in science education in particular, with many projects funded by the US National Science Foundation and the European Union, coming under the “STEM” banner (European Commission, 2022, Honey et al., 2014).

As exemplified by the quote above, many authors erroneously credit Judith Ramaley at the US National Science Foundation (NSF) with the first use of the term in 2001, suggesting she re-ordered the acronym previously in use, SMET, as it sounded vulgar (Breiner et al., 2012; Donahoe, 2013). Cavanagh and Trotter (2008) actually quote Ramaley herself in repeating the narrative that the term is relatively new:

A number of educators credit Judith A. Ramaley, a former director of the National Science Foundation’s education and human-resources division, with being the first person to brand science- and math-related subjects as STEM. Before Ramaley took that job in 2001, the more widespread label was SMET, which was used at conferences and in grant proposals by the NSF, a federal agency based in Arlington, VA. “I always thought it was terrible,” says Ramaley of the SMET initials. “It made me think of many things, but none of them had to do with science and technology.” (para. 14).

However, we have discovered that, in 1962, Dr Harold Foecke was employed at the US Office for Education as a specialist for engineering education (Engineering Education, 1968). Government records at the time place him in the Professional and Technical education section of the Higher Education Programs Branch (National Center for Educational Statistics, 1962). The journal, *Engineering Education*, detailing his achievements for an award, reports that: “In 1964 he was made Chief of the Science, Technology, Engineering, and Mathematics (STEM) Section, in addition to his specialist duties (Engineering

Education, 1968, p. 35). This, in 1968, is the earliest mention we can find of the use of the acronym STEM to mean Science, Technology, Engineering and Mathematics. We have been unable to corroborate the existence of this section in US government documents recording the work of the Higher Education Programs Branch in which Foecke was employed. Records for this period are incomplete and hard, if not impossible, to find. Regardless of whether the section existed or not, *Engineering Education* uses the term STEM to mean science, technology, engineering and mathematics, in that order and as early as 1968; the term is, thus, over 50 years.

Over the years, there appears to have been a divergence between STEM education in schools and STEM education in informal sectors, in terms of their underlying rationales, a point which is critical when planning collaborations between the two sectors. The origins of this divergence can be traced back to at least the 1950s. For example, in 1959, the US President's Science Advisory Committee argued for the need to expand the science horizons of the public and particularly in education:

The advances of science and technology need special attention to the end that (1) all citizens of modern society acquire reasonable understanding of these subjects and that (2) those with special talents in these fields have full opportunity to develop such talents. (Quoted in Office of Education, US Department of Health, Education and Welfare, 1965, p. 23).

This statement implies two types of science and technology focused education one to promote careers in those subjects and the other for broader scientific literacy. This point was reiterated 6 years later, in "The Progress of Education in the United States" report which suggested that there was an awareness among the nation's citizens that "science and technology have a basic role to play in the free world's present and future welfare and security" (Office of Education, US Department of Health, Education and Welfare, 1965, p. 27). The report identified three purposes for the science education reform movement:

1. Insuring a level of scientific literacy equal to, and prepared for, the demands placed on society by science and technology.
2. To provide specialized education in science to students who, after they have finished school, will constitute the creative, scientific and engineering manpower of the future.
3. To provide opportunities for students to pursue science as an interesting endeavour on a cultural basis. (Ibid)

This multi-faceted vision of STEM education is, perhaps, more coherent than many current versions and it is one, perhaps, that should underpin the development of future hybrid collaborations. As we have said above, to look forward for STEM education, we also need to look backward.

Another look back, this time to 1988, shows that equity and diversity were important dimensions of STEM policy initiatives even then. In that year, the Office of Undergraduate Science, Engineering and Mathematics was created in the Directorate for Science and Engineering Education (National Science Foundation, 1988a). It had a program entitled 'Career Access Opportunities in Science and Technology for women, minorities and the disabled' (National Science Foundation, 1988b). This program brought the four disciplines together and shows an early focus in STEM education on widening participation and social justice. This aspect of STEM education is also clear in a 1994 US National Science Foundation report that stated that the Division of Undergraduate Education aimed to:

Strengthen and ensure the vitality of undergraduate education in science, mathematics, engineering and technology for all students [...] Particular emphasis is placed on improving access for all segments of United States society, including populations underrepresented in science, mathematics and engineering studies and in technical and teaching careers. (National Science Foundation, 1994, p. 28).

Future hybrid collaborations will also need to address issues of equity and diversity and, perhaps, encourage the use of culturally responsive STEM teaching. This approach might be challenging in the US given the current political situation. The fact that equity and diversity are as much an issue in 2025 as they were in the 1980s suggests that there are no quick wins to be had and that systemic change continues to be required.

Writing about 'Using email and the internet in science teaching' in 1994, Robinson (1994) notes that "The [US] federal government has set goals for improving the level of STEM education in the belief that the US economic well-being and standard of living can only be protected by maintaining world standards in science and math education (1994, p. 229). As well as noting that this paper was written several years before the supposed invention of the term by Judith Ramaley, we can begin to see a greater policy focus on school education rather than out-of-school provision. Robinson explains that as a consequence of the government's goals, it was funding: "two key areas in K-12 science education: [...] training for the teachers of science and mathematics; and [...] the development of better curriculum

materials and instructional strategies to teach science and mathematics (p. 230).

### **The status of STEM subjects and the increasing fluidity of the meaning of the term**

In the past, not all sciences had equal status within STEM (Wong et al., 2016). In previous STEM initiatives in the UK, funding was allocated primarily to physics and mathematics with some attention paid to chemistry. Biosciences received far less funding (Wong et al., 2016). In part, this was because biology was (and is) a very popular subject at both school and university level and so was not believed to need any additional support, but it was also because biology was perceived to be less important to the economy than the mathematics skills developed through mathematics itself and the physical sciences (ibid). What is also clear from Robinson's paper is that by 1994, mathematics had risen in status and sat alongside science to the possible detriment of technology and engineering. A focus on science and mathematics, and especially science, in STEM was noted by Wong et al. (2016), as was the view of UK mathematics teachers that STEM could be problematic if it led to an emphasis in mathematics as a support for science education (Wong & Dillon, 2019). The role of the different disciplines in STEM is one that future collaborations between formal and informal institutions will need to address.

Over the years, there has been increasing fluidity in the meaning of STEM, which is something else that future collaborations will need to address. Gonzalez and Kuenzi (2012), in a report for the US Congress, note that there are varied definitions for which subjects are included as part of STEM even within federal agencies. They suggest that the NSF definition is broader and includes psychology and the social sciences, whereas other federal agencies generally exclude social sciences and focus on "mathematics, chemistry, physics, computer and information sciences, and engineering" (p. 2). Note that this second list does not include the biosciences or the health sciences (Wong et al., 2016). It could be argued that education to address wicked problems needs the most inclusive conceptualisation of STEM possible which is something more likely to be afforded by informal STEM institutions, if only because, unlike schools, they are not organised into subject silos.

### **The challenge posed by STEM's multiple meanings**

Wong et al. (2016) suggest that STEM is viewed differently depending on where you stand. In school, science and mathematics, particularly in the UK, are the subjects that really matter, but in the world of business, technology and engineering are, perhaps, more important. To

policy makers, the focus of STEM is the supply of people with the skills needed by the STEM sector of the economy, whereas in schools, STEM is often interpreted as a rationale for interdisciplinary work (Honey et al., 2014; Wong et al., 2016).

In many countries, STEM rarely means a programme of technology education (Williams, 2011) and in the UK neither does it include engineering at school level (Wong et al., 2016). McComas and Burgin (2020) similarly note the tendency to use STEM to refer to science and mathematics, ignoring the T and the E. In the US, engineering is very visible in the Next Generation Science Standards (Christian et al., 2021) and engineering design has been promoted as the basis for a number of STEM programmes, but that is not common worldwide.

We would argue that STEM collaborations between formal and informal institutions need to acknowledge the different perspectives held in schools and in business and industry, otherwise they are likely to fail. Also important is the historic focus of school STEM initiatives on maintaining the 'STEM pipeline' which is often at the expense of broader visions of science (literacy) for all (Cannady et al., 2014). This tension, though, is not always evident and initiatives such as Operation Earth in the UK seem to acknowledge that it is possible to promote careers in STEM with a wider perspective:

Operation Earth is a national STEM programme that engages, inspires and involves school-age children and their families and communities with NERC's world-leading environmental science research. The programme highlights the relevance of contemporary environmental science issues to everyone's daily lives and to society's future. It is led by ASDC and Phase 1 was created in partnership with three development partners—Dynamic Earth, Eden Project, and Natural History Museum—with scientific expertise from NERC. (Association for Science & Discovery Centres, undated).

The rise in awareness of cross-disciplinary environmental issues such as climate change and biodiversity loss might benefit STEM collaborations. Increasingly, the biosciences are seen as crucial to addressing the wicked problems facing society. Future STEM collaborations will need to recognise their importance and not simply replicate previous inequalities between disciplines.

### **What might success look like?**

As with science collaborations, there are already examples of STEM initiatives that link informal science institutions with schools. Inspired by President Barak Obama's 2011 State of the Union speech, a number of large-scale transformative initiatives were set up. One such is 100Kin10 which aimed "to recruit and develop 100,000

excellent teachers in STEM fields by the year 2021” (D’Souza, 2018).

A more modest UK programme was organised by the Brooklands Museum:

Engineers and scientists from organisations like McLaren F1, Airbus, the NHS, and Haleon, joined over 400 students for the first-ever Brooklands Innovation Academy. Part of the National Science Summer School programme, co-founded by Professor Brian Cox CBE and Lord Andrew Mawson OBE, the all-day event celebrated innovation, human endeavour, and entrepreneurship. (Brooklands Museum, 2022).

## Conclusions

First, the imprecision in definitions and history have allowed STEM to develop a multiplicity of often contradictory meanings, including STEM being simply a collection of subjects and STEM referring only to interdisciplinary work (McComas & Burgin, 2020). That said, we are convinced that there is a need for greater numbers of hybrid collaborations between educators in formal and informal settings. As Bevan et al. noted many years ago in terms of science education, these STEM initiatives will require “more intentional and strategic deployments of resources, leading to collaborations that build on the particular affordances and strengths of different institutional types to meet shared goals.” Examples of successful initiatives exist already, such as the UK’s Project Earth but more could be done.

While some STEM collaborations have been set up, there is a need for many more, not least because the wicked problems facing us require inter- and multi-disciplinary approaches. In planning school/museum, school/science centre, etc., collaborations, we need to learn from the history of STEM. Early concerns of STEM included these subjects being necessary for the prosperity and security of the nation. Recognition that there were inequalities in STEM participation, and that rectifying such inequality would require both research and action, seems to have arisen in the 1990s. The discourse of the importance of STEM subjects for economic prosperity is still seen, as is the concomitant concern with equality of access to STEM careers. Collaborations are more likely to succeed when potential partners share their understanding of what STEM means and why it is important. A project where one partner believes that it is primarily about getting more people into science and engineering jobs and the other thinks it is about developing STEM literacy for all, is likely to have problems in delivering a coherent programme. An appreciation that STEM means different things to different people, and within different sectors, is a fundamental foundation for collaboration.

Many questions, however, remain. These include why these four disciplines were initially brought together and why seemingly similar disciplines such as medicine (and sometimes biosciences) were frequently excluded. Whether STEM collaborations should broaden to incorporate direct reference to medical science or the arts and humanities is beyond the scope of this paper but these are clearly important points to ponder.

Finally, as a sidenote, the contradictions evident in the varied use of the term STEM were apparent, if not from the beginning, then at least from when the prevalence of the term STEM increased, at the turn of the century. Given the diversity of meanings ascribed to the term, we would encourage authors to state the definition they are using in any publication. That an array of meanings has been in use for many decades means that it is not appropriate to try to state any singular definition as the most authentic.

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## Author contributions

V.W. and J.D. have conceptualised and co-authored this paper in relatively equal amounts.

## Availability of data and materials

No datasets were generated or analysed during the current study.

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## Competing interests

The authors declare no competing interests.

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