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Using the family resemblance approach to inform STEAM education

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Abstract

In this article, we use the family resemblance approach as a framework to contribute to the debate about the similarities and differences between the constituent disciplines of STEAM (science, technology, engineering, arts and mathematics) and to explore the implications for education. The family resemblance approach has been used in science education in various ways, for instance, in teacher education and undergraduate teaching and as an analytical tool for examining science curricula and assessments. The relevant sense of application of the family resemblance approach for our purposes in this article is that it is a framework that has the potential to differentiate the disciplines underpinning STEAM. We explore the utility of the family resemblance approach for clarifying what is meant by the nature of STEAM and, subsequently, we elaborate on some practical examples drawn from a project conducted in Hong Kong with Year 7 (12–13-year-old) students to illustrate how the use of the family resemblance approach can help articulate a contrast of nature of science and the arts in school activities.

Keywords STEAM; family resemblance approach; nature of science

Introduction

There has been growing interest in the integration of science, technology, engineering, arts and mathematics (STEAM) in education (for example, NAEA, 2017). Much has been debated about what STEAM may or may not mean in education, and about the boundaries across the individual disciplines represented, for example, the boundaries between technology and engineering. Furthermore, the scope of the arts within STEAM remains vague (Colucci-Gray et al., 2017). Some stakeholders limit the arts to the narrow meaning of art (that is, visual arts) (for example, NAEA, 2017), while others add performing arts such as music and dance and literary arts (for example, Haroutounian, 2019). There has also been discussion about what distinctions there may be between the constituent disciplines of STEAM, for example, in relation to the nature of science and engineering (Park et al., 2020a).

In this article, we use the family resemblance approach (FRA) (Erduran and Dagher, 2014) as a framework to elaborate on what is meant by STEAM. We draw on the similarities and differences between example constituent disciplines of STEAM (for example, science and the arts) and explore the implications for education in the context of secondary science education. FRA is a framework used within science education that characterises different fields of science, such as chemistry, physics and biology, in terms of the resemblances. Different fields of science have similar aims, such as obtaining accurate data. However, there may also be domain-specific differences between different fields of science. For instance, what counts as observation in astronomy and chemistry can be nuanced (Irzik and Nola, 2014). In the case of astronomy, the evidence is often historical in nature, based on observations of events that happened in the past, given the time it takes for light from the stars to travel to the Earth. In the case of chemistry, data about the impact on the volume of a gas can be collected in the present time by increasing the pressure at constant temperature. Such differences in the nature of evidence and observations are worth noting as nuances between these fields.

FRA has been applied in science education in different ways. A recent special issue of the journal *Science & Education* (Barak, 2023) was dedicated to various aspects of FRA usage in science education, building on previous studies. For example, previous work in various countries included the integration of FRA in teacher education in Türkiye (Kaya et al., 2019) and teaching undergraduate students in Germany (Petersen et al., 2020). FRA has also been used as an analytical tool for examining STEM curricula in Spain (Couso and Simmaro, 2020) and science assessments in Hong Kong (Cheung, 2020). Students' understanding of the nature of science (NOS) has been investigated at the level of the elementary school (Akbayrak and Kaya, 2020) and the university (Akgun and Kaya, 2020). A series of studies focusing on the analysis of textbooks on their coverage of NOS have been conducted in Lebanon (BouJaoude et al., 2017) and South Korea (Park et al., 2020b). A significant FRA contribution in these studies has been the articulation of NOS in a more holistic manner than previously conceived. By introducing a series of cognitive, epistemic, social and institutional categories to characterise science as a system (Erduran and Dagher, 2014), the framework has advanced a systematic and inclusive characterisation that can be traced in a range of contexts. For example, the framework has enabled researchers to trace across national contexts how the socio-institutional dimensions of science are consistently under-represented in science curricula from various parts of the world, such as Italy (Caramaschi et al., 2022), Norway (Korsager et al., 2022) and Taiwan (Yeh et al., 2019).

For the purposes of our article, the relevant sense of FRA application is that it is a framework that has the potential to distinguish different lines in enquiry (Park and Brock, 2023). In other words, given that FRA is based on the premise that some disciplines share particular similarities to warrant their being named science, a similar analogy is used for comparing and contrasting the different sub-fields of STEAM, that is, science, technology, engineering, arts and mathematics. It is important for students to learn what is similar and different across school subjects, because there may be ways of thinking and reasoning that are specific to these subjects. Students' knowledge, as well as their expectations of what the subjects entail, can thus be calibrated accordingly. For example, even in the case of science disciplines, there are variations that may cause unrealistic expectations. Whereas in the case of physics there is a tendency towards mathematisation and in biology and chemistry there is a strong emphasis on classification of qualitative properties (Scerri, 1991). Expecting quantification in a chemistry context that is more about classification of qualitative properties (for example, colour changes as indicators of chemical reactions) would thus be unreasonable. If such disciplinary nuances are not clear, students may potentially develop unreasonable expectations and attitudes towards different subjects. For example, they may indicate that biology is not a proper science because it is not mathematical enough. Similarly, in the context of STEAM education, it is important to characterise the nature of each sub-discipline, so that students can differentiate their aims, values and methods.

Hence, we explore the utility of FRA for clarifying what is meant by the nature of STEAM. Our discussion raises two main questions. First, what is STEAM education? Here, we explore some key themes related to STEAM education to provide a broad overview of the literature. Second, what is the nature of STEAM? Here, we are interested in raising further questions about how the disciplines underpinning STEAM can be characterised. Given that STEAM is multifaceted and composed of various sub-disciplines (for example, science, engineering and mathematics), it is beyond the scope of this article to explore all possible permutations of integration. Rather, we focus on the integration of science and the arts as an example and explore how the FRA framework may help characterise such integration. After addressing these questions, we illustrate the integration of science and the arts by using a secondary school student's drawing and a potential teaching activity to show how the use of FRA can begin to elaborate on the nature of STEAM in educational contexts. Our emphasis is on science, because FRA was originally conceptualised for science, but in this article, we are applying it to STEAM more broadly. However, no inference should be drawn about any hierarchy between the sub-domains of STEAM, for instance, in terms of the superiority of science among them. In other words, by drawing links between science and the arts using FRA, we are simply providing an example of how some aspects of STEAM, admittedly limited, can be characterised. Future research can build in a systematic manner how other aspects of STEAM can further be articulated.

What is STEAM education?

There is now a plethora of research on the integration of science, technology, engineering, arts and mathematics (STEAM) in education (for example, Colucci-Gray et al., 2019; Lewis, 2015). However, the precise nature of what the 'arts' element is remains unclear (Colucci-Gray et al., 2017). In some cases, the A in STEAM has been defined in the narrow sense of 'art' (that is, visual arts) (for example, NAEA, 2017), while in others, music and dance and literary arts (for example, Haroutounian, 2019) are also included. Some researchers even argue that STEAM should be inclusive of humanities (for example, Lewis, 2015). A broad conceptualisation of STEAM has also been considered in a holistic framework that integrates the humanities and social sciences (Erduran et al., in press).

In some conceptualisations of STEAM, the arts have been viewed as enhancements of STEM education, where the arts can provide pedagogical support for the learning of core features of science, technology, engineering and mathematics. For example, role play in drama can be a pedagogical strategy to support students in portraying molecules, biological cells, energy and behaviour of electrons, while students integrate their conceptions of phenomena with scientific explanations (Braund and Reiss, 2019). Some criticism has been voiced about this approach, namely by Lewis (2015), who argues that the separation of the arts from STEM is problematic, and that the arts are already an integral part of STEM. The emphasis on the arts is observed in recent perspectives on STEM education that go beyond arguments about economic growth, and address the fundamental purposes of teaching STEM, such as social inclusion, democracy and sustainability (Chesky and Wolfmeyer, 2015).

Traditionally, as school subjects, the arts focused on personal choice, while science stressed problem-solving activities (Gardner, 1971), as individuals can choose the form of arts, such as combination of colours, based on their personal experiences and aesthetic preferences (Palmer et al., 2013). Given the increasingly elevated status of the arts in STEAM education, educators are now advocating an explicit integration of the arts in STEM learning (Liao, 2016; Wynn and Harris, 2012). Some authors have argued that the arts and science can be integrated in STEAM programmes in order to enhance students' sensitivity towards the environment, intuition and creativity (Mun, 2022; Root-Bernstein, 1999). The arts can also provide students with aesthetic experiences which motivate them to participate in STEM activities and use emotions to make sense of their STEM experiences (Wickman, 2006). For example, aesthetic experiences in learning STEM nurture students to notice contextual details and develop their imaginations of creative solutions, which leads to a bridging from 'everyday' arts to 'disciplinary-specific' arts (Caiman and Jakobson, 2022; Ferguson et al., 2022).

While arguments for STEAM education have now become mainstream, the precise nature of STEAM itself needs further articulation. Is the nature of STEAM a combination of the nature of distinct disciplines, or is there an emergent characterisation of STEAM? Such questions have been raised in a similar vein about the nature of STEM, for example in the context of a special issue of the journal *Science & Education* (Erduran, 2020), which presents several theoretical and empirical investigations about NOS. The fundamental question remains about the meaning of the nature of STEM disciplines. In terms of NOS, some researchers have focused on several salient characteristics of science that are agreed on (for example, Lederman et al., 2002; McComas et al., 1998), whereas others have proposed NOS frameworks that embrace a wider range of aspects in various sciences, bearing in mind the complexities of disagreements among scientists (Allchin, 2016; Dagher and Erduran, 2017; Hodson and Wong, 2017). In the following section, we discuss briefly the nature of the disciplines constituting STEAM. In so doing, we aim to address a fundamental philosophical question about STEAM and offer some suggestions for educational applications.

What is the nature of a discipline?

Given that STEAM is a conglomerate of different disciplines, namely science, technology, engineering, arts and mathematics, it is crucial to question what the nature of each discipline entails, and how these disciplines relate to each other. Although there may be pedagogical reasons for infusing the arts, for instance, in educational contexts, what are the implications for students' learning in terms of what the arts are in relation to, say, science? How do the different disciplines compare in terms of their similarities and differences? It is vital that students understand the answers to such questions, because each discipline can only address particular problems, and they have their own missions. For example, while some arts may have a strong aesthetics component in trying to depict beauty (for example, Michaelangelo's David statue and its depiction of beauty in human form), the priority for science problems may have little to do with aesthetics in a similar sense – although the use of art in science may strive to be simple and easy to communicate. Beauty in science or mathematics may also have a different sense from the point of view of the professionals. Whatever the case might be, the issue at hand is that there may be disciplinary or subject-specific nuances to how each aspect is conceptualised and positioned. As argued previously, if such disciplinary nuances are not clear, students may potentially develop unreasonable expectations and attitudes towards different subjects. For example, according to Spall et al. (2003), students in a physics programme of study tended to see biology as easier, less conceptual and less mathematical than their own subject. By contrast, although students in a biology programme also saw physics as more conceptual and mathematical than biology, they viewed biology as more interesting. Such stark generalisations about the nature of biology and physics, for instance, are unfounded, given a range of conceptual and mathematical tools that both endeavours can employ (Longo and Montévil, 2017). Situating the aims, objectives, methods, ethos and culture of each constituent discipline of STEAM will help clarify potential confusion and enable productive examination of these disciplines at the level of the classroom.

A relevant area of research within science education for considering how a discipline works is the so-called nature of science (NOS). The NOS literature has a track record since at least the 1960s, and significant reviews exist (Lederman et al., 2014) that can potentially inform STEAM education. NOS has been characterised from various perspectives, including Features of Science (Matthews, 2012), Whole Science (Allchin, 2011) and the Consensus View (McComas et al., 1998). Lederman (1992) refers to NOS as the values and assumptions fundamental to science and its knowledge development, which include independence of thought, creativity, tentativeness, empirical basis, subjectivity, testability, and cultural and social embeddedness.

A relatively recent perspective on NOS is the FRA (Erduran and Dagher, 2014; Irzik and Nola, 2014). This approach emphasises the resemblance between different disciplines or domains of science as the main criterion for classifying them as science. At the same time, it stresses that while different sciences resemble each other in a way that the members of a biological family might, there are also differences between them. Specificity of particular domains are described by Irzik and Nola (2011: 596) as follows:

> Astronomical theories (before the advent of radio 'telescopes') appeal to human telescopic observations, but astronomy is not an experimental science; experiments are simply not possible

in this field. Again consider the characteristic of making predictions. Again, most sciences aim to make predictions, especially novel predictions, but not all of them succeed. For example, celestial mechanics is very good indeed in predicting planetary positions. In contrast, even though evolutionary biology does a wonderful job of explaining the evolution of species, it has not produced any mathematically precise, novel predictions. Similarly, earthquake science does a good job of explaining why earthquakes occur, but so far it has failed to predict the times of major earthquakes, though it is pretty successful in predicting their locations.

According to Erduran and Dagher (2014), FRA represents NOS as a cognitive-epistemic and socio-institutional system (see Figure 1). As such, it is a meta-perspective on the different aspects of science, which includes a range of categories related to the epistemic and cognitive aspects of science, such as the aims and values, methods and practices of science and scientific knowledge, as well as the socio-institutional aspects, such as scientists' professional activities, scientific ethos, social certification and dissemination of scientific knowledge, and social values (Erduran and Dagher, 2014). Characterised as such, FRA accounts for a broad range of categories that can be applied to different domains, and it has been used as such in contrasting nature of science and engineering (for example, Barak et al., 2022).

Figure 1. The FRA wheel (Source: Erduran and Dagher, 2014: 28)

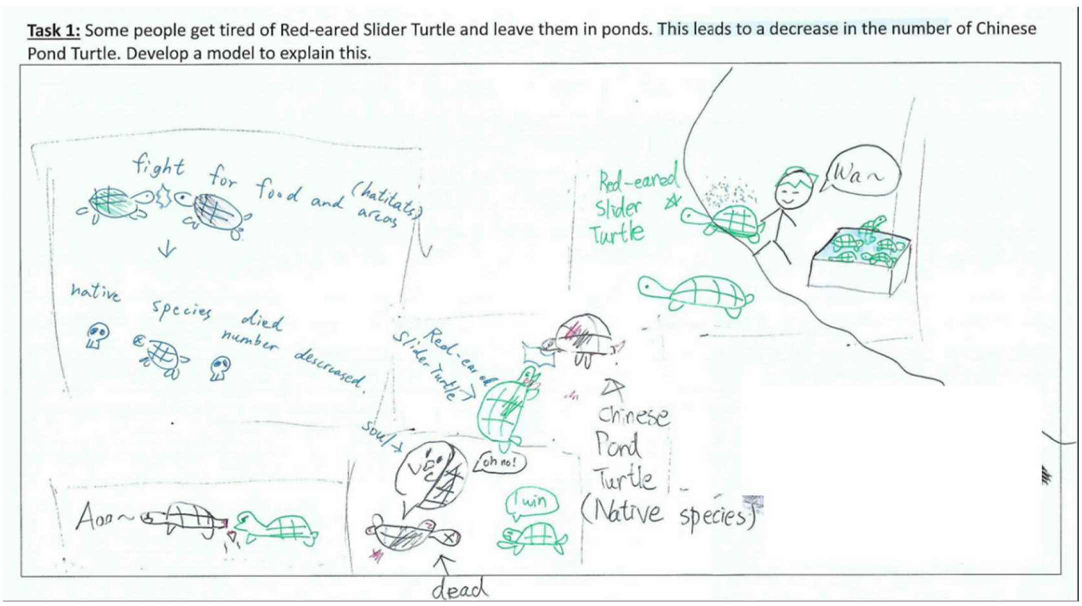
FRA has been used in science education and science communication, illustrating its versatility in adaptation for different purposes (Cheung et al., 2023). Numerous studies focusing on the analysis of science textbooks using the FRA framework have been conducted. Park et al. (2020b) have analysed Korean physics textbooks about NOS. Their study illustrates that most textbooks did not cover the broader social, economic and political aspects of NOS. McDonald (2017) has used FRA to investigate representations of NOS in Australian junior secondary school science textbooks, focusing on biology textbooks more particularly. The author observes that although there were many opportunities for including FRA categories such as professional activities, social values of science, social certification and dissemination, the textbooks presented some missed opportunities by ignoring their coverage. BouJaoude et al. (2017) analyse Lebanese textbooks for their depiction of NOS. Using FRA as an analytical framework, the authors demonstrate that there was variation in how the different subject textbooks covered key categories, such as scientific methods.

FRA provides some categories that can potentially be applied to differentiate the constituent disciplines of STEAM. In application to STEAM, particular FRA categories such as practices may be used to clarify how different domains articulate them. As an example, while modelling may be common in all domains of STEAM, particular aspects may be quite distinct. While scientists may generate models through evaluating evidence, artists may choose to incorporate emotive elements in modelling that transcend a drive to represent reality. By capturing disciplinary nuances, STEAM education can ensure that the characteristics of the constituent disciplines are contrasted, thereby enriching understanding. Indeed, such investigations have already been carried out in the context of a contrast of science and engineering (for example, Barak et al., 2022). Further contrasts can be built across the STEAM disciplines by using the FRA, given that it encompasses a class of epistemic and non-epistemic ideas. We conjecture that asking students to reflect on similarities and differences in epistemic aspects between two domains can broaden students' knowledge of how STEAM works in formal classroom settings. Many scholars have argued for an explicit and reflective approach to develop learners' epistemic and non-epistemic ideas, as simply engaging students in classroom activities cannot help students develop these ideas (Khishfe, 2013; Khishfe and Abd-El-Khalick, 2002). Similarly, to engage learners in reflecting on epistemic and non-epistemic ideas behind STEAM domains, teachers can provide structured opportunities to discuss epistemologies of STEAM in relation to instructional contexts, specifically for their aims and values, knowledge, practices, methods and socio-institutional aspects.

As an example, let us consider the contrast between science and the arts. While science and arts practices are different in some ways, they may also share some common approaches that students can use to construct scientific models and augment artistic meaning. The common features may involve aspects such as nature, generality, justification and audience (Berland et al., 2015):

- *Nature*: Both scientific modelling and applying artistic principles aim to show how and why things take place. Scientific modelling disentangles the cause-and-effect relationships between biological and physical components in an ecosystem (Zangori and Forbes, 2015), while artistic principles can be applied to describe aesthetic and cultural events (Gude, 2007).
- *Generality*: Both scientific modelling and applying artistic principles aim at generality, but in different senses. The aim of scientific models is to explain current scenarios, and to predict future situations (Schwarz et al., 2009), if new elements are added into the ecosystem. Specifically, the scientific model in Figure 2 explains why the population of native species decreases, and accounts for what happens if more foreign species are introduced into a local habitat again. The artworks aim for readers' recognition of its beauty, modernity and colourfulness (Augustin et al., 2012).

Figure 2. An example of a student's work from a modelling activity

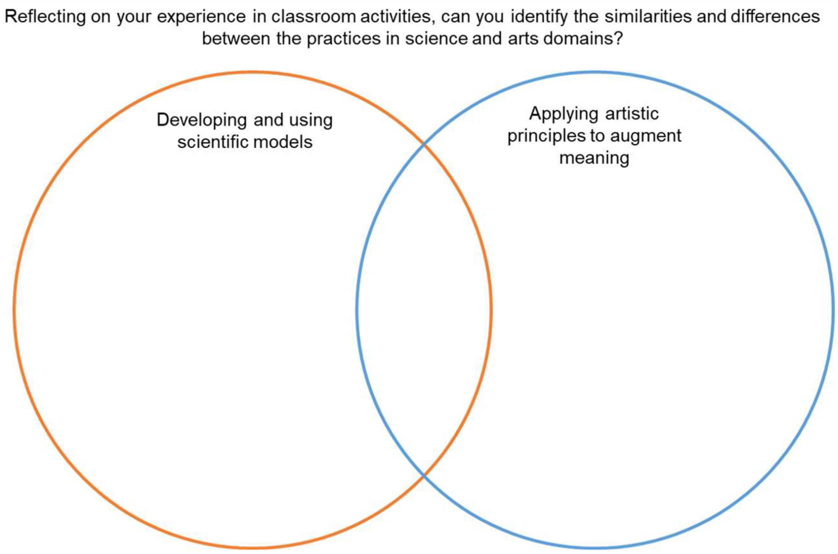


- *Justification*: Science and arts products are constructed based on the evidence available. In this case, the causal relations between introducing foreign species and the decrease in population of native species are based on observations and data (Erduran and Dagher, 2014) of interaction between organisms. Artworks can also be created based on the identification and interpretation of images, which is known as iconography as a branch of art history (Prown, 2001). In this case, the appearance of a turtle is drawn based on students' noticed elements in a real picture of two turtle species.
- *Audience*: The process of constructing scientific models and artworks involves negotiation and building ideas among group members. In terms of modelling, students negotiate based on their

knowledge of competition between two turtle species. They try to mimic scientists to communicate their knowledge products to other scientists as the audience (Pluta et al., 2011). In terms of application of artistic principles, students discuss the use of colours, shapes and arrangement of diagrams which facilitate the meaning making of readers (Kress, 2010).

The Venn diagram in Figure 3 is a representational tool which can help to highlight similarities and differences between science and art practices. It resonates with the underlying philosophy of FRA (Park et al., 2020a). Such a representation tool can provide students with explicit opportunities to reflect on similarities and differences between a scientific practice (for example, developing and using scientific models) and an artistic practice (applying artistic principles to augment meaning). Developing and using scientific models seem to be unrelated to applying artistic principles to augment meaning. However, with the aid of the Venn diagram, students can write down commonalities shared between the scientific practice and the artistic practice. Although it might not be possible to reinforce all epistemic and non-epistemic practices of all STEAM domains in a single lesson, teachers can selectively address one or two of these ideas in two domains that are suitable for a specific instructional context (Hanuscin et al., 2011). Structural opportunities can reorient secondary school students to reflect on the intentions, processes and outcomes of integrating various STEAM domains (Mejias et al., 2021).

Figure 3. An example of activity that explicitly reflects on similarities and differences between developing and using scientific models and applying artistic principles to augment meaning



In summary, the FRA does not prescribe what the distinction criteria should be when addressing the similarities and differences between science and the arts. Rather, it offers a set of categories around which they can be compared on a case-by-case basis. For example, if the epistemic aims and values of the sciences and the arts are considered, they can be contrasted with a set of examples. While empirical adequacy and accuracy might be significant epistemic aims of science disciplines (Irzik and Nola, 2014), the arts may not necessarily be concerned about such aims, but rather may be more preoccupied by aims such as emotional expression. The example provided is intended to showcase ways of integrating science with the arts, which can be covered in both science and arts lessons depending on the teaching goals. The intention here is not to be prescriptive about which aspects of STEAM are integrated, nor is it to argue that such cross-subject work be done in only particular subject lessons. Rather, the illustrations are meant to provide some concrete instances of potential integration.

Example integration of the nature of science and arts in the classroom

As the preceding discussion suggests, the FRA adopts an interdisciplinary approach (Park et al., 2020a; Perignat and Katz-Buonincontro, 2019) to epistemic and non-epistemic aspects of science, which can then potentially be extended to technology, engineering, mathematics and the arts. In an interdisciplinary approach, the nature of each domain shares some similarities in their epistemologies, while each domain also has its own discrete characteristics (Smith and Paré , 2016; Thuneberg et al., 2017). The premise of FRA is to place epistemic and non-epistemic characteristics of arts and STEM domains as mutually instrumental and pedagogical tools for education, specifically with the view of the equal importance of all domains, and the aim of advancing students' understanding of both arts and STEM fields (Mejias et al., 2021). An understanding of the disciplinary nature of these fields can potentially help educators to clearly communicate goals and big ideas of learning to students (Basham and Marino, 2013), hence, fostering students' cognitive, emotional and social engagements with arts and STEM equally.

Given the literature background on the nature of STEAM is quite conceptual (Mejias et al., 2021; Quigley et al., 2017), we provide a concrete and practical illustration, with a description of the modification of an ordinary example of a science activity, how secondary education can explicitly address similarities and differences in the nature of two STEAM domains, science and the arts. The example we presented in Figure 2 was drawn from a research project where the second author co-planned instruction with the participating teacher on the FRA framework, with the aim of teaching Year 7 (age 12 to 13) students epistemic and non-epistemic ideas in Hong Kong. The data presented in this article involve students creating a model to account for the cause and effect of introducing foreign species to the habitat of native species. The scenario describes to the students that the original native species in ponds was the Chinese pond turtle. As local people bought the Brazilian red-eared slider turtle overseas, and introduced them into local ponds, the native species, the Chinese pond turtle, decreased in population. The original design of this lesson was intended to elicit students' reflection on NOS based on the FRA framework. However, in this article, we extend and modify the lesson ideas, such that the lesson can elicit students' reflection on NOS practices, and on the nature of arts practices as well.

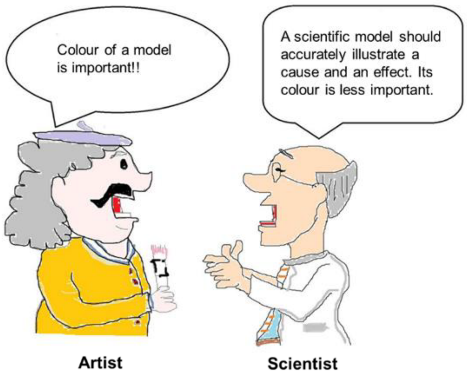
In the activity, students applied the scientific practice of modelling to conceptually represent the competition between two species of turtle (Figure 2). This model accounts for the change in a number of local species when a foreign species is introduced to the ecosystem. Meanwhile, they also applied arts practices to construct their models, applying artistic principles to augment meaning (Mejias et al., 2021), in this case the meaning of competition. Students used different colours (green and black) to illustrate different species of turtles, as well as red scratches on the bodies of turtles. The artefact also made use of thinking bubbles to visualise the emotions of participants who released red-eared slider turtles, and the mental thoughts of turtles. These artistic elements enable the scientific models to illustrate the competition between two species leading to a decrease in the population of Chinese pond turtles, spiralling their representation from everyday arts to science-specific arts.

As demonstrated in this example, students used different scientific and artistic practices to create a model that explains the ecological relationship between two turtle species. To extend this activity to reflection on the nature of STEAM, the Venn diagram in Figure 3 can be added after the activity of modelling, which facilitates explicit discussion of how scientific practices and artistic practices can be integrated with each other. In Figure 2, some of the concepts represented in the student's drawing are rather complex. For instance, the concept of competition in the natural world is likely to be difficult for students to express either in words or in pictures. Combining the scientific practice of modelling with artistic expression helps students to represent and communicate the concept. In other cases, other FRA categories can potentially be introduced. For example, in the context of the classroom where multiple representations emerge, students' work can be discussed and evaluated collectively in an effort to build on the social certification and dissemination aspects of FRA. Here, the scientific aim is to explain the concept of competition in the natural world. From an artistic point of view, the aim may be considered to be clarity of representation of the animals by using appropriate drawings. Explicit discussions can be carried out to compare and contrast such practices and aims in the sciences and the arts. FRA provides an overall road map of categories that can be used to structure such discussions. Other pedagogical strategies, such as engaging students in arguing the differences between the arts and science, could potentially foster students' understandings of the nature of STEAM. Situating students in debates between stakeholders in STEAM disciplines could promote students' understanding of epistemology behind scientific practices (Erduran and Mugaloglu, 2012).

In our proposal for modifying existing activities for students to engage in reflecting on the nature of STEAM, different pedagogical strategies can be combined, and the content of the activity can be informed by FRA. Consider the activity in Figure 4, where students are presented with a concept cartoon with two alternative claims presented by an artist and a scientist. They are asked to support either the view of the artist or that of the scientist. Here, the strategy of argumentation (for example, Erduran et al., 2004) is used to foster debate and discussion. In terms of FRA, the focus again is on the practices and aims of the sciences and the arts. After engaging in such an activity, students can reflect on what models mean in the areas of science and arts. From the perspective of an artist, aesthetic elements of models, such as colour, may be important. However, for scientists, articulation of cause-and-effect relationships is likely to be more important than aesthetic elements. The concept cartoon will exploit the emergence of epistemologies of modelling, such that the differences between scientific models and arts models can be highlighted. By eliciting students' responses on the argumentation between the artist and the scientist, teachers can also question students on the similarities between a scientific model and an artistic model.

Figure 4. Example to promote argumentation about models in the arts and sciences

The cartoon below shows a debate between an artist and a scientist about characteristics of model.



Whose view do you agree with? Why?

Conclusions and discussion

We have addressed some central questions about the nature of STEAM constituent disciplines. In so doing, our intention was to clarify for teaching and learning purposes how science and the arts, as an example subset, can be contrasted and integrated using the FRA lens. Articulation of all possible combinations of the disciplines constituting STEAM was beyond the scope of this article. However, our approach may be useful for researchers who wish to explore other potential contrasts in the future. As students navigate school subjects, there is hardly space in the curricula to have reflective and explicit conversations about the nature of the disciplines, at least from a STEM point of view (for example, McComas, 2015). The use of FRA as a guiding framework can potentially help curriculum developers, as well as teachers and learners, in unpacking the similarities and differences between the STEAM disciplines. We have illustrated the utility of FRA with some examples from student work, and with a potential teaching activity using a concept cartoon to explain how the theoretical ideas around FRA can be transformed for educational practice. We have focused on the relationships between science and the arts in the context of the FRA category of practices and epistemic aims, highlighting the nuances in modelling and objectives in each domain.

Given the diversity of disciplines represented in STEAM, it is beyond the scope of this article to provide an exhaustive account of how FRA can serve as a tool in differentiating the various combinations

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of the nature of each constituent discipline. Rather, we have aimed to provide an example using the FRA framework to illustrate how some categories, such as practices and aims, can be situated in two aspects of STEAM – science and the arts. Clearly, even these domains can be subdivided further into various sciences and the arts. Regardless of which discipline is being represented, we argue that FRA can bring some clarity and specificity to reflect on what makes a discipline a discipline, how it compares to others and how a coordinated approach to STEAM education may be followed to ensure that students understand each discipline in context. It would be unfortunate to mix up the aims of science with the aims of the arts, and have expectations that one is somewhat limited when compared to the other. For example, the arts may not have an element of accuracy in some schools of practice, and judging the arts against this criterion using a scientific aim would not be appropriate. Students will have meaningful discussions about STEAM when they can reflect on the nature of the disciplines relative to their internal structures, which can be explicated by frameworks such as the FRA. Future research and development efforts can extend the scope of this article to generate further areas of contrast across the STEAM disciplines. Overall, the article contributes to the literature on the applications of FRA in educational contexts (for example, Barak, 2023).

Declarations and conflicts of interest

Research ethics statement

The authors declare that research ethics approval for this article was provided by the University of Oxford ethics board.

Consent for publication statement

The authors declare that research participants' informed consent to publication of findings – including photos, videos and any personal or identifiable information – was secured prior to publication.

Conflicts of interest statement

The authors declare no conflicts of interest with this work. All efforts to sufficiently anonymise the authors during peer review of this article have been made. The authors declare no further conflicts with this article.

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