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SI: NATURE OF STEM

Inquiring into the Nature of STEM Problems

Implications for Pre-college Education

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Abstract
Around the world, there is a growing interest in integrated STEM (science, technology, engineering, mathematics) education. Many of the calls for integrated STEM emphasize the need for students to engage with complex STEM problems that cut across multiple fields. Yet there is a need to clarify the nature of those problems and differentiate STEM problems from those of different kinds. This conceptual work examines the nature of STEM problems in order to inform pre-college educational efforts in STEM. A typology is introduced that situates STEM problems within a broader space of problems within STEM and non-STEM fields, and the characteristics of STEM problems are described. The typology and characteristics are then applied to different approaches to STEM instruction. A key conclusion is that many integrated STEM education efforts tend to focus on STEM problems that are narrowly framed and that do not include attention to social, cultural, political, or ethical dimensions. However, alternative instructional approaches exist that re-introduce those missing dimensions. If STEM education is to prepare students to grapple with complex problems in the real world, then more attention ought to be given to approaches that are inclusive of the non-STEM dimensions that exist in those problems.

Keywords Nature of STEM · Nature of science · Nature of engineering · Nature of mathematics · STEM education

1 Introduction

Around the world, educational policy is being increasingly directed toward STEM education (e.g., Caprile et al. 2015; Education Council 2015; Marginson et al. 2013; The Royal Society 2014). The emphasis on STEM is often justified by pointing out the relevance of science,

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technology, engineering, and mathematics to issues of societal significance. Consider the language from a US 5-year strategic plan on STEM education:

> Advances in science, technology, engineering, and mathematics (STEM) have long been central to our Nation's ability to manufacture better and smarter products, improve health care, develop cleaner and more efficient domestic energy sources, preserve the environment, safeguard national security, and grow the economy. (Holdren et al. 2013, p. vi)

A similar perspective can be seen in a STEM policy document from the European Union:

> …the EU aims to promote the agenda, research and innovation in the energy field and to strengthen Europe's industrial base... Areas in which STEM skills are of particular relevance are considered as strategic by the "Jobs, Growth and Investment Package" (infrastructure, notably broadband and energy networks, as well as transport infrastructure, particularly in industrial sectors; education, research and innovation; and renewable energy and energy efficiency). (Caprile et al. 2015, p. 8)

At times, the term "STEM" is used in policy documents simply as a shorthand way of referring to science, technology, engineering, and mathematics, although precisely which fields fall under that umbrella varies (Breiner et al. 2012; Gonzalez and Kuenzi 2012; Xie et al. 2015). The National Science Foundation in the USA, for example, simply uses the STEM label to refer to the distinct fields in which it funds research (Sanders 2009). Within education, however, the meaning of STEM often extends beyond reference to education in a set of discrete fields. As described by Breiner et al. (2012), "the most important modern conception of STEM education might be the notion of integration – meaning that STEM is the purposeful *integration* of the various disciplines as used in the solving real-world problems" (p. 5, emphasis added). That viewpoint is similarly conveyed by the National Research Council's (2014) report on STEM integration:

> More generally, many real-world contexts and problems typically involve more than one of the disciplines. For example, designing alternative energy systems that run on solar or wind energy, understanding how to maintain a clean water supply, or maintaining fragile ecosystems will require knowledge and practices from across the STEM disciplines. (p. 20)

Within the integration perspective, STEM education is conceptualized as an approach that emphasizes how STEM fields converge to address problems that require science *and* technology *and* engineering *and* mathematics rather than "*or*" (Breiner et al. 2012; Bryan et al. 2016; Bybee 2010, 2013; English 2016, 2017; Kelley and Knowles 2016; Moore et al. 2014; Rosicka 2016). From this perspective, integrated STEM instruction should therefore involve engaging students in STEM problem-solving (Bryan et al. 2016; Johnson 2013; Kelley and Knowles 2016; OECD 2017; Stohlmann et al. 2012; Tytler et al. 2019). The connection to real-world problem-solving is, of course, not new or unique to integrated STEM education. Preparing students to engage with real-world problems has roots in progressive education (DeBoer 1991; Schiro 2012) and the work of Dewey (1938), and is considered important within many contemporary educational efforts in science, technology, engineering, and mathematics (International Technology Education Association 2007; National Research Council 2012; National Governors Association 2010; Ojose 2011). The novel perspective offered by STEM education is its emphasis on the integration of a specific set of disciplines to address those real-world problems.

Given the association between integrated STEM education and problem-solving, several questions arise: Exactly what kinds of problems are STEM problems? What are the identifying characteristics of those problems? How do STEM problems differ from simply scientific or mathematical problems, or problems in non-STEM fields? Those questions are vitally important for classroom teachers as well as teacher educators and curriculum designers who endeavor to engage students in integrated STEM instruction. Without a clear understanding of the nature of STEM problems, the "STEM" label lacks any specific meaning. Already there is a proliferation of curricula that market themselves as "STEM" (e.g., Accelerate Learning 2020; Morgan and Ansberry 2017; Museum of Science, Boston 2007), the kinds of problems present in those materials vary widely. Not all problems are STEM problems, and from an instructional perspective, there is a need for clarity around the kinds of problems with which students should engage in the STEM classroom.

The purpose of the present work is to develop an understanding of STEM problems that is informative for instructional decision-making in STEM education. One objective is to position STEM problems within the broader space of problems that exist in the world. The rhetoric of STEM education accurately highlights the fact that many important real-world problems require more than just a single discipline to address. Yet although many problems exist that are "bigger" than what science or mathematics can address on their own, many problems are also "bigger" than what even all of the STEM fields can address. And at the same time, although many problems demand multiple disciplines, the problems addressed within individual disciplines remain important. Understanding the nature of STEM problems means placing them within that broader landscape of problems. The second objective of the present work is to establish a set of characteristics of STEM problems that can assist teachers and educators in identifying whether a given problem ought to be classified as a STEM problem. I begin by examining prior efforts to describe the nature of STEM and indicate how an approach that focuses on the nature of STEM *problems* is likely to be more informative. I then introduce a typology of STEM problems, outline a set of core characteristics of STEM problems, and in the final section I provide specific examples of STEM education that are consistent (and inconsistent) with the framework outlined in this paper. Of note, various scholars have called for additions to be made to the STEM acronym, most notably the inclusion of the arts (and sometimes humanities) to produce STEAM (e.g., Connor et al. 2015; Quigley and Herro 2016). For the purpose of the present work, I focus on STEM rather than any of the extended acronyms. Future work might investigate whether the nature of STEAM problems differs substantially from STEM; such questions are beyond the scope of the present investigation.

1.1 Prior Efforts to Describe the Nature of STEM

The present work is not the first attempt to address the nature of STEM. In a 2014 editorial, Peters-Burton identified elements of the nature of STEM by examining characteristics of each of the four STEM fields and locating "ideas where each of the characteristics overlap and where they are different" (p. 99). She found that all of the disciplines "depend on iterative cycles of inquiry that lead to the development of valid and productive ideas" (p. 100), noting several key differences in how each of the disciplines engages in inquiry. She then asserted that STEM is:

> characterized by the human endeavor of anticipating outcomes based on background knowledge, making sense of what is observed, the use of logical reasoning, approaching unknowns systematically, and the necessity of transparency for the purposes of replicability and evaluation. (p. 100)

The characteristics proposed by Peters-Burton are mostly unobjectionable, although it is not clear whether they necessarily apply to each STEM field (parts of mathematics—number theory, for instance—have little to do with anticipating outcomes). The issue, however, is that in order to locate overlapping characteristics of fields with distinct differences, the list of features proposed by Peters-Burton are generic and could easily apply to most fields of study or even most cases of complex human reasoning. For example, chefs anticipate outcomes based on background knowledge, make sense of what they observe, use logical reasoning, and approach unknowns systematically. The products of a chef's work are scrutinized by diners and critics, and when made public, chefs' recipes are subjected to replication and further scrutiny. Yet few would argue that chefs are STEM professionals or that cookery is an example of STEM.

Although they were not specifically addressing the nature of STEM, a similar problem was encountered by Antink-Meyer and Brown (2019) in their attempt to find overlap between the natures of science and engineering. They advanced the claim, for instance, that both science and engineering are empirically based, but went on to explain how the nature of observations, inferences, and interpretations of data differ substantially between the two disciplines. Given those differences, one is left to wonder whether the statement that both disciplines are "empirically based" carries significant meaning. After all, if differences can be so easily ignored, any number of empirically based disciplines can be identified (e.g., history, sociology, economics), and one could again point to the example of cookery as an empirically based field. This illustrates a core challenge of trying to locate overlap between fields that have substantial differences: in order to locate similarities, one must appeal to generalities that become uninformative.

More recently, Akerson et al. (2018) described an inquiry into the nature of STEM that also involved examining the nature of its composite fields. In an editorial describing their work, they concluded STEM not to be a "real" construct with any unique nature. Instead, they argued that "STEM itself is a socially constructed label that is in response to economic and global pressures" (p. 5). In their view, STEM is *merely* a label circulated in policy initiatives. The most they could say about the nature of STEM is that it seems to be similar to the nature of science, with the addition that STEM is "interdependent" (p. 5). Unlike Peters-Burton (2014), Akerson et al. (2018) found the search for a nature of STEM to be a doomed project.

Although previous efforts to examine the nature of STEM were not successful in certain respects, they are nevertheless informative. The approach taken by both Peters-Burton (2014) and Akerson et al. (2018) was to begin their investigations with the nature of the individual STEM fields. That approach is sensible if STEM is conceptualized as simply a way to reference the four STEM fields. If STEM is a little more than a shorthand for science, technology, engineering, or mathematics, then the nature of STEM would simply be the characteristics of those fields that overlap. Evidently, within that conceptualization, the nature of STEM is, at best, broad and generic. However, if STEM is conceptualized as an interdisciplinary space beyond the individual STEM fields, then examining the natures of the individual STEM fields is not a sufficient approach. The more productive approach that is pursued in the present work is to examine the nature of STEM *problems* rather than seek overlap among the STEM fields. A focus on problems is more consistent with the way that integrated STEM education is conceptualized (Breiner et al. 2012; Kelley and Knowles 2016; Moore et al. 2014; NRC 2014) and avoids the needs to locate similarities across what are, in many respects, distinct fields.

2 Establishing a Framework for the Nature of STEM Problems

2.1 Problems Within Individual STEM Fields

As discussed above, describing the nature of STEM problems entails positioning them in relation to other classes of problems. An understanding of the nature of STEM problems should make clear how they differ from scientific ones, mathematical ones, problems in non-STEM fields, and problems that transcend STEM. To begin the work of positioning STEM problems, the following sections outline the kinds of problems addressed by science, technology, engineering, and mathematics. The following sections do not attempt to give comprehensive accounts of the nature of science, technology, engineering, or mathematics. More thorough treatments of those topics can be found elsewhere (e.g., Pleasants and Olson 2019; Pleasants et al. 2019; Erduran and Dagher 2014; Hacking 2014). The fields are not taken up in the order of S-T-E-M, but rather in an order that will best illustrate the similarities and differences between the fields.

2.1.1 Scientific Problems

Within the STEM acronym, the "S" typically refers to the natural sciences as opposed to the social sciences, and as such can be generally conceptualized as oriented toward creating knowledge of the natural world. Science therefore addresses problems of knowledge, which might arise when descriptions of phenomena are incomplete, or when no satisfactory explanation exists for certain phenomena, or when logical inconsistencies are detected within the body of scientific knowledge (Chalmers 2013, p. 113; Laudan 1977; Stewart and Rudolph 2001). In very general terms:

> *Science addresses problems of knowledge related to the natural world. Knowledge includes fundamental ideas as well as applications of those ideas to the natural world.

Note that knowledge of the natural world is expanded both when fundamental ideas are developed and also when those ideas are applied to novel situations. For example, Einstein's theory of General Relativity addressed problems of fundamental knowledge of the natural world: the nature of space and time in relation to gravitation. After the theory was introduced, many scientific problems were raised regarding the applications and implications of the theory. Shortly after the theory was presented, solutions to Einstein's field equations were sought, resulting in the identification of possible singularities in spacetime: black holes. Astronomers have applied General Relativity's description of gravitational lensing in order to determine the masses of distant galaxies. How to apply General Relativity is as much a scientific problem as how to develop the fundamental idea.

2.1.2 Mathematical Problems

Like science, mathematics is concerned with developing knowledge, but the knowledge that mathematics develops is "about" something very different from that of science. The "objects" of mathematical knowledge are abstract, unlike the natural phenomena that are the focus of science. Mathematics deals with abstract entities such as numbers, shapes, equations, spaces, and operations (Hersh 1997, pp. 13–18). The precise nature of those entities is a subject of ongoing debate (Balaguer 2001; Connes et al. 2001), but those disagreements are ancillary to the task of describing mathematical problems. Whatever mathematical entities exactly *are*, the task of mathematics is to expand knowledge about the characteristics and properties of those entities, how they work, how they can be used, and the relationships between them (Devlin 2012; Gowers 2008). Although mathematics differs from science in terms of its objects of study, in broad terms, the nature of mathematical problems can be described in a similar format as scientific ones:

> *Mathematics addresses problems of knowledge related to mathematical entities. Knowledge includes fundamental ideas about the properties of and relationships between those entities as well as how those ideas can be applied.

Like science, mathematical problems can be oriented toward the development of fundamental knowledge or applications—the familiar distinction between "pure" and "applied" mathematics.

2.1.3 Technological Problems

Technology occupies a peculiar status within the STEM acronym. Unlike science, mathematics, and engineering, technology is not a field of study but rather is a broad set of objects, systems, and processes (Dusek 2006, pp. 26–37; Mitcham 1994, pp. 151–154). One can speak reasonably about the kinds of problems taken up in science, engineering, or mathematics because they are reasonably well-defined disciplines made up of scientists, engineers, and mathematicians. Technology, in contrast, is not a discipline made up of technologists. Professional labels exist for "technologist" and "technician" (cf. Canadian Council of Technicians and Technologists 2019), but technological work extends far beyond what is done by individuals bearing those labels. Because the scope of technology is so large, technological problems are best described in broad terms. Technologies are products of human intentions and enable humans to do things they would not otherwise have been able to do (Kroes 2012, p. 3; Mitcham 1994, pp. 230–235). Technological problems can therefore be viewed as problems of human intention:

> *Technological problems are about enabling certain human actions via the creation or novel use of objects, systems, and processes.

2.1.4 Engineering Problems

Engineering is concerned with the design and development of technology, which means that it represents a subset of the broader field of technological work. In other words, engineering problems are necessarily technological problems, but not all technological problems are necessarily engineering problems. For instance, engineering focuses on the functional rather than esthetic aspects of technology (Kroes 2012, p. 7). Engineering is also focused on the design of technological systems rather than the physical production of technologies. Even when engineers design systems of production, they are not themselves the ones who carry out the operation of those systems (Dym and Brown 2012; Kroes 2012, p. 127; Vincenti 1990, ch. 6). Engineering also leverages more theoretical knowledge and analytical approaches to technological design (Mitcham 1994, pp. 213–215).

Engineering differs substantially from science and mathematics in that it is not primarily aimed at producing abstract, generalizable knowledge. Instead, engineering is primarily concerned with the development of technologies, bound to a particular context (Dym and Brown 2012; Kroes 2012, p. 133). Engineering does at times produce new knowledge, some of which is abstract in that it can be applied across a range of contexts (Houkes 2009). The activity associated with the production of engineering knowledge is often called "engineering science," which shares characteristics with science and mathematics (Bucciarelli 2009). Knowledge produced by engineering science, for instance, is subjected to peer review via journals and must adhere to evidentiary standards (Banse and Grunwald 2009; Channell 2009; Vincenti 1990). But unlike science or mathematics, knowledge production is not the primary goal of engineering (Banse and Grunwald 2009; Dym and Brown 2012; Kroes 2012, p. 134). Engineering science produces knowledge for the reason that it can then be applied directly to problems of technological development that are the focus of engineering (Bulleit 2013).

> *Engineering problems are a subset of technological problems that focus on the functional design, development, and analysis of technological objects and systems.

2.1.5 Interactions

As is clear from the preceding sections, each STEM field addresses problems that are substantively different from one another. Yet many interactions exist between the fields, because problems in one field often relate to and raise problems in another (Ihde 2009; Kroes 1995; Pitt 1995). A historical example can be found in the development of heat engines during the 17th and 18th centuries, described by Kranakis (1982). How to develop a heat engine that can do useful mechanical work and operate with maximum efficiency raised primarily technological and engineering problems. Yet in addressing those problems, many scientific problems were also raised about the nature of heat, temperature, energy, and the behavior of gases. Scientists' attempts to address those problems began the development of the field of thermodynamics. Mathematical problems were in turn raised when the behavior of heat engines and thermodynamic processes began to be represented in mathematical terms, and thus required new applications of mathematical ideas.

Scientific problems often raise technological and engineering problems because much experimental scientific work is highly dependent on complex technological instruments (Latour 1987; Pitt 1995; Volti 2017, p. 67). This is especially true in the era of modern "big science" projects. Detecting the Higgs boson, for instance, required the development of the enormously complex Large Hadron Collider at CERN. It also raised multiple mathematical problems including ones of interpreting data and ones related to the mathematical representations that underlie the Standard Model of particle physics. The fact that problems in one STEM field often raise problems in other STEM fields is, of course, one reason why the fields are often discussed as a unit.

Although interactions exist between the fields, the most logical and informative name for what scientists do is nevertheless "science" rather than "STEM." Similarly, typical activities of mathematicians should likely be labeled "mathematics," even though mathematicians often investigate problems that are brought forth by lines of scientific inquiry or by engineering problems, and even though many mathematicians use computational technologies. Mathematics, in other words, is about addressing mathematical problems just as science is about addressing scientific ones. Labeling science or mathematics as “STEM” is unproductive because it erases the important differences between those fields and the kinds of problems they address. It also fails to indicate how STEM refers to a class of problems that are different from those of its constituent fields.

2.1.6 The Value of Disciplinary Perspectives

The preceding sections indicate an important tension within discussions and descriptions of STEM. On the one hand is a recognition that many problems of societal significance are broader than those addressed by an individual field such as science or mathematics. An impulse therefore exists to view disciplinary boundaries as problematic and counterproductive, often expressed in calls to tear down disciplinary “silos” (e.g., Gilbert 2008). As described by Wang et al. (2011), “Currently, STEM disciplines are taught in silos. But the nature of the work of most STEM professionals blurs the lines between disciplines. Therefore, teaching STEM disciplines through integrating them would be more in line with the nature of STEM” (p. 1). In a comprehensive account of the arguments to tear down disciplinary boundaries in academia, Jacobs (2014) describes how critics of disciplinary structures argue that disciplinary boundaries stifle innovation and are incompatible with the fact that “real-world problems are bigger than any one discipline can handle” (p. 18).

The anti-disciplinary impulse, however, sacrifices what is valuable in recognizing the distinctions between the STEM fields. The boundaries that exist between fields are not arbitrary. By focusing on a relatively narrow range of problems, disciplines develop specialized approaches that are carefully tuned to address those problems. The complex set of scientific methods, the norms and values held by the scientific community regarding what evidence is legitimate, and the ways that the scientific community evaluates knowledge claims can all be viewed as tools that have been honed to address the specific class of problems science addresses. Similarly, mathematicians and engineers have developed their own sets of knowledge, methods, and norms that are highly aligned to the kinds of problems that exist in their respective fields. Erasing the boundaries between the STEM fields risks sacrificing what makes the specialized knowledge and practices of those fields powerful. A thoughtful approach to STEM must simultaneously recognize the value of disciplinary distinctions while also making room for interdisciplinarity.

2.2 STEM Problems

As many voices within STEM education make clear, many problems of societal significance are sufficiently complex that they cannot be localized to a single field (Breiner et al. 2012; Bryan et al. 2016; Bybee 2010, 2013; English 2016, 2017; Kelley and Knowles 2016; Moore et al. 2014; NRC 2014). Some concrete examples of those problems will be useful to have at hand, and the policy documents quoted in the introduction (Caprile et al. 2015; Holdren et al. 2013; NRC 2014) provide the pertinent examples that are listed in Table 1.

The problems in Table 1 represent the kind of complex issues that the National Research Council (2014) argues “involve more than one of the [STEM] disciplines” (p. 20). Some clarification, however, is needed regarding the term “involve.” A productive way to describe the involvement of the different STEM fields is to conceptualize complex problems as *amalgams* of intersecting sub-problems. If those sub-problems can be framed as scientific problems, mathematical problems, technological problems, or engineering problems, then the

Table 1 Examples of STEM Problems

Designing alternative energy systems
Maintaining a clean water supply
Maintaining fragile ecosystems
Maintaining the environment (more generally)
Developing infrastructure for broadband, energy, and transportation
Improving public health
Promoting economic growth
Safeguarding national security

specialized knowledge and methods of those fields can be effectively brought to bear. Viewed in this way, STEM problems are positioned within a hierarchy of complexity and are composed of problems aligned with individual fields.

The hierarchical conceptualization of STEM problems is complicated, however, by the fact that many of the problems in Table 1 have components that are aligned with both STEM and non-STEM fields. For instance, maintaining a clear water supply raises engineering problems about how technologies can be developed that either cleanse unsafe water or prevent contaminants from entering the water supply. It includes scientific problems about how different chemicals in water interact with one another and affect human health. It raises mathematical questions regarding how water systems can be represented and analyzed in mathematical terms. Important to note here is that, as described above, scientific problems (as well as mathematical ones) need not be about generating new fundamental knowledge about chemical interactions; scientific (and mathematical) problems can be ones of how existing ideas can be applied to new situations. Maintaining a clean water supply also includes political questions about the control over the water supply. It includes economic problems regarding who bears the costs of the water supply. It raises moral and ethical questions about how who is responsible for the harms of unclean water. In similar fashion, the complex problem of improving public health includes components related to science, technology, engineering, and mathematics, but it is so complex that sub-problems could also be identified in sociology, history, ethics, political science, psychology, and economics, among others.

Not all complex problems necessarily include components from such a wide range of fields, and certain problems in Table 1 do not appear to extend much beyond the STEM fields. For instance, developing new energy infrastructure is primarily an engineering problem. To illustrate, consider the specific example of developing infrastructure for wind energy using modern wind turbines. The primary problems involved in developing that technology are engineering ones, related to how turbines can be improved in term of efficiency, cost of production, reliability, and other technical dimensions (e.g., Bhutta et al. 2012). Scientific problems are also present, because a desirable property of any energy technology is for it to have minimal negative environmental consequences. Once constructed, wind turbines produce little pollution, but they still interact with the environment in ways that warrant study, for instance, how they affect the microclimates of the agricultural fields in which they are typically placed (Rajewski et al. 2016). Addressing those engineering and scientific problems will likely require the use of mathematical modeling, which will in turn produce mathematical problems. Although the wind turbine example seems most aligned with STEM fields, problems in non-STEM fields can nevertheless be identified. For instance, there are political and economic questions regarding the extent to which governments should subsidize or otherwise support the technology. There are also land rights issues (e.g., whether turbines should be allowed in cities and towns) and questions about how to equitably weigh the tradeoffs that inevitably come with any new technology.

In sum, problems of societal significance are often sufficiently complex that they are amalgams of components aligned with both STEM and non-STEM fields. Even highly technological problems can include dimensions from outside of STEM. The way that complex problems are *framed* is therefore of critical importance, because that framing will often determine which components are foregrounded and which recede to the background.

2.2.1 Framing STEM Problems: a Typology

To more effectively situate STEM problems in relation to other classes of problems, a typology of problems will be informative. When framed in broad terms, many problems include sub-problems aligned with a wide array of fields, as illustrated by the example of wind turbine development discussed above, yet problems can be framed such that certain components are brought to the foreground. Consider, for instance, the following two framings of the wind turbine problem:

1) We want to develop wind turbine technology that efficiently produces large amounts of electricity at a low cost, with minimal measurable impact on the environments in which they are placed.
2) We want to develop wind turbine technology that will improve the economic, environmental, and social well-being of the communities in which they are placed. We want technologies that bring benefits to the community stakeholders while minimizing any negative impacts on those stakeholders.

The first framing of the problem is what I will call a *Pure STEM* problem: it has been cast in such a way that it can be decomposed entirely into component problems aligned with science, technology, engineering, and mathematics. The second framing is what I will call a *STEM-Relevant* problem because while sub-problems can be identified in each of the STEM fields, there are many dimensions to the problem that are aligned with non-STEM fields. In other words, STEM-Relevant problems exhibit an even greater level of complexity than Pure STEM problems in that they are amalgams of Pure STEM problems and problems from other fields of study. The two classes of STEM problems are represented in Fig. 1. In both cases, note that engineering problems are situated as a specific class of technological problems (as described above).

Interestingly, many of the real-world problems that are discussed as motivating the need for STEM education (see Table 1) would be categorized as STEM-Relevant problems rather than Pure STEM problems. Problems of societal significance are often broad in scope and complexity, and it is not necessarily surprising that they would include many non-STEM elements. Nevertheless, the fact that such broad and complex problems are used to motivate education specifically in STEM rather than other equally relevant fields (e.g., the social sciences and humanities) is intriguing. Of course, some problems are neither Pure STEM problems nor STEM-Relevant problems; I will call those *Non-STEM* problems. Some non-STEM problems are connected to only a single STEM field. Consider, for instance, a technological problem that is not connected to science, engineering, or mathematics:

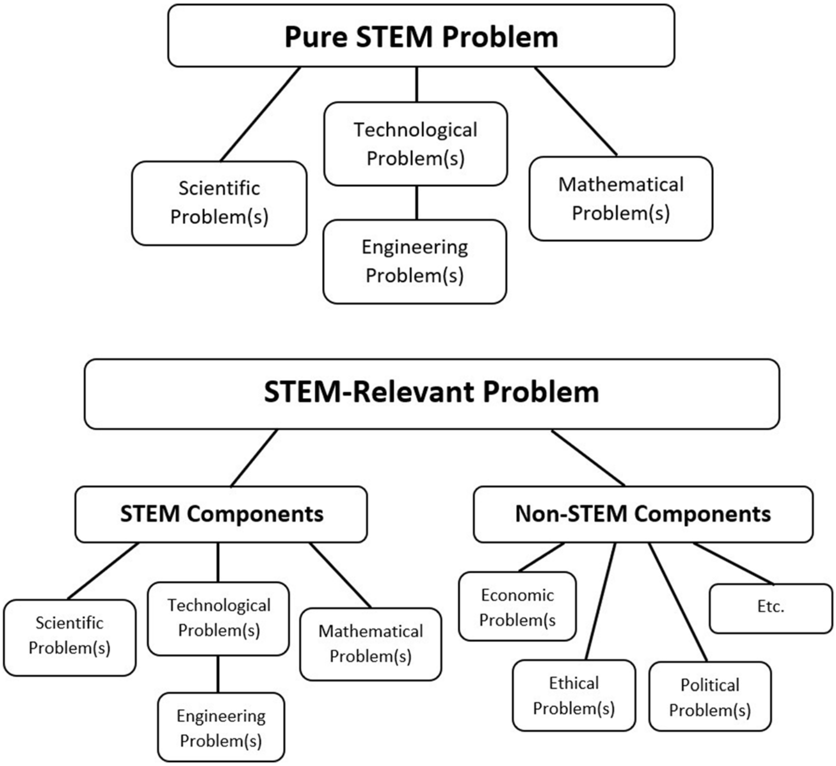

Fig. 1 Representation of the STEM problem types

Example A: Non-STEM Problem

The production of ceramics is a technological activity that has existed for millennia. Although ceramics can be produced in high-tech industrial settings, they are also still produced in artisanal spaces by individual craftspeople. The central problem confronting the ceramics craftsperson is how to create in the material world an object that is consistent with the functional and esthetic goals of the craftsperson. To accomplish that complex technological task, a craftsperson must utilize deep knowledge of how to use relevant technologies (e.g., kilns and pottery wheels) to skillfully manipulate various materials (e.g., clays and glazes) to create a desired product.

Non-STEM problems can also be more overtly centered in topics that fall outside the scope of the STEM fields. The problem described in the example below is one that raises questions for public policy, politics, economics, and sociology. Some mathematical questions might be raised because certain aspects of the situation can be mathematically represented. But the other STEM fields are not represented and the problem therefore would be classified as Non-STEM.

Example B: Non-STEM Problem

Housing shortages exists in many regions around the world, and a serious problem facing many communities is how to provide adequate housing for residents. A serious question for communities is how to provide housing in an *equitable* manner, because housing is not just a question of supply. Different ethnic and racial groups often face unequal access to housing, as do poor members of a community; unequal access often results in disproportionately high rents paid by those individuals (Desmond and Wilmers 2019). The problem, then, is how to determine what equitable access to housing means in a community, and what members of a community (through policy actions, provision of services, etc.) can do to promote equitable access.

2.3 Characteristics of STEM Problems

Having provided some concrete boundaries around what qualifies as a STEM problem, I now turn to the characteristics of STEM problems. I will focus mainly on the characteristics of Pure STEM problems here, as those characteristics also pertain to the components of STEM-Relevant problems that are purely STEM. As defined above, Pure STEM problems are ones that can be decomposed into sub-problems from each STEM field and that can be fully addressed by the STEM fields. Describing the characteristics of those problems involves describing the properties that make STEM problems distinct from other types; it is therefore a task, to an extent, of demarcation. Posing the demarcation task does not imply that there exist necessary/sufficient criteria that can be used to assign the label of "STEM"—the history of demarcation projects in the philosophy of science teaches us to be leery of such claims (Laudan 1983). Instead of criteria, I follow contemporary approaches in the philosophy of science (Pigliucci 2013) and instead seek out a set of characteristics of STEM problems that together form a "family resemblance" rather than a set of rigid criteria. Unlike a necessary criterion, each characteristic in the family resemblance approach identifies an important aspect of STEM problems that need not necessarily apply to all instances. Similarly, a specific problem might show one or more characteristics yet still be a clear case of non-STEM. Identifying key characteristics will not only assist in resolving the demarcation question above; they will also form a description of the nature of STEM. The "family resemblance" approach has been productively used to describe the nature of science (Erduran and Dagher 2014; Irzik and Nola 2014).

Table 2 presents a set of characteristics that provide a detailed view of the nature of STEM problems. Genuine cases of STEM problems will exhibit many, though not necessarily all, of those characteristics. Likewise, cases of non-STEM problems will exhibit few, though not necessarily none, of the characteristics. Each characteristic should further be considered a continuum rather than a binary in that a specific case might exhibit the characteristics to a greater or lesser extent. The following sections provide a more extensive description of each characteristic and how each characteristic applies to illustrative examples.

Foreground Novel Technologies Because STEM problems necessarily include engineering and therefore technological components, STEM problems therefore relate to technological design and development, which implies *novel* technologies. A STEM problem might pertain, for instance, to the development of an entirely new technology, a novel extension of an existing technological system, or the translation of an existing technology to a new context. Novelty does not necessarily mean *radical* novelty, which is why "novel" is a more

Table 2 Characteristics of STEM problems

1. Foreground novel technologies
2. Foreground S-T-E-M knowledge
3. Foreground S-T-E-M methods
4. Context-specific
5. Reductive

appropriate term than "innovative." Innovation represents a special case of novelty and although it is emphasized in modern discourse, it does not describe all technological development (Russell and Vinsel 2019).

Not all technological problems exhibit novelty. Routine repair and maintenance work, for instance, involve a variety of technological problems that are not novel. That does not imply that the work is unimportant; in many respects, routine technological work is of the utmost importance as it allows vital systems to operate. In addition, the creation of technological products is not necessarily a case of novelty. Paper clips, for instance, are technological objects that are regularly produced by multiple companies. The underlying technology of the paper clip (including the manner of production), however, has changed little in recent years (Petroski 1996, ch. 2), and each new paper clip that is produced therefore does not represent an instance of novelty.

In Example A, described above, the problem of ceramics production does not strongly exhibit novelty. Although all craftspeople engage in the production of technologies, production alone does not exhibit the characteristic. Novel technologies *can* come from crafts work and have done so throughout history; however, crafts work is generally not oriented toward novel technological development but rather is concerned with the skillful production of existing technologies (Kroes 2012, p. 127; Mitcham 1994, p. 213). Crafts work therefore does not necessarily completely lack the characteristic of novelty, but it exhibits that characteristic to a relatively small extent. In contrast, the wind turbine is an example of a novel technology in that modern turbines are a departure from the windmills of the past. They differ not only from traditional windmills in their scale, but also in their components that enable their integration with the modern electrical grid.

Foreground S-T-E-M Knowledge Each of the STEM fields has a knowledge base that is utilized to address problems within that field. Science and mathematics are primarily interested in further developing and applying their respective knowledge bases, and engineering also involves knowledge production when it is necessary for addressing specific engineering problems. As amalgams of sub-problems in the STEM fields, STEM problems therefore involve knowledge production and applications from each of those fields. The Manhattan Project, for instance, generated vast amounts of engineering knowledge specific to the context of atomic weapons as well as more general knowledge in nuclear physics and applied mathematics (Hoddeson et al. 1993). The wind turbine example also demonstrates this characteristic as indicated by the vast of scholarly papers that have been published by scientists and engineers seeking to better understand how wind turbines function and how they interact with their local environments (e.g., Bhutta et al. 2012; Dalili et al. 2009; Rajewski et al. 2016). In contrast, the crafts work described in Example A is not demanding of scientific, engineering, or mathematical knowledge. The ceramics craftsperson is certainly knowledgeable about the technology at hand, but does not need to reach for the more theoretical knowledge bases of science, mathematics, or engineering (Mitcham 1994, p. 213).

Foreground S-T-E-M Methods In addition to specialized knowledge bases, each of the STEM fields utilize well-established methods that have been developed to address the kinds of problems specific to that field. There does not exist a single universal "scientific method" for addressing scientific problems (Chalmers 2013, p. 149) nor does there exist a single universal process for designing technologies (Lawson 2006, Chapter 3) or process of mathematical inquiry (Hersh 1997). Rather, each field uses a range of approaches to analysis and inquiry that are tailored to the nature of the scientific, engineering, and mathematical problems at hand. In general terms, one can describe different styles of reasoning that are employed within science and mathematics such as deductive logic, experimentation, and modeling (Crombie 1994; Kind and Osborne 2017). Within scientific sub-fields, methods become more specialized and specific to that field. The methods of an experimental ecologist, for instance, are different than those of a theoretical physicist. For mathematics as well, the methods employed will depend on the kind of problems under study. Some mathematical problems require the methods of rigorous proof, but other problems are more aligned with locating new methods of calculation—for instance, finding a new set of solutions to a differential equation of interest (Gowers 2008). Engineering also employs some of those modes of reasoning, and also has developed specialized approaches to design tasks, such as formalized methods for comparing alternative designs, for weighing costs and benefits, and for modeling complex systems (Bucciarelli 1994; Dym and Brown 2012; Vincenti 1990, ch. 4). Because STEM problems are composed of problems from the individual fields, the methods of those fields are therefore foregrounded in STEM problems. Which *specific* methods are foregrounded will depend on the specific scientific, technological, engineering, and mathematical components of the broader STEM problem.

Context-Specific Science and mathematics often aim to develop knowledge that are context-general rather than context-specific (Chalmers 2013, p. 44; Hersh 1997). Technological and engineering problems, however, are sensitive to economic, technological, and social circumstances (Kroes 2012, p. 133). STEM problems, therefore, are not context-general but context-specific. To develop wind turbine technology, for instance, one must be aware of the existing electricity infrastructure as well as governmental regulations that necessarily vary from place to place. Wind turbines will also be introduced into a set of economic circumstances that dictate the cost of the technology as well as the value of electricity that is produced. Wind turbines will also be used in specific environmental contexts, and their effects on the local environment (e.g., agricultural fields, coastal regions, population centers, grazing pastures) will depend on those contexts. Therefore, although STEM problems involve the use of abstract knowledge, they nevertheless include contextual elements.

Reductive Although STEM problems are tied to a specific set of contextual circumstances, how those circumstances are addressed is an important characteristic of STEM problems. For any real-world problem, a seemingly limitless set of potentially relevant factors can be identified. To make the problem tractable, one must identify which of those factors will be given attention and which will not. Only by reducing the complexity of situations in the real world can the disciplinary tools of the STEM fields be effectively deployed. The mathematical relationships embedded the physical laws of mechanics, for instance, are most readily applicable to situations with relatively few interacting components. The intractability of the notorious three-body problem, for instance, illustrates how rapidly situations can exceed the capacity of the analytical tools of science and mathematics (Gowers 2008).

The STEM fields tend to frame problems reductively, in which many aspects of complex are decomposed into smaller, simpler, and more tractable units by ignoring certain complicating factors or reframing those factors in more familiar terms (Bucciarelli 1994; van Riel and Van Gulick 2019; Vincenti 1990). Engineering provides a particularly clear example. As noted previously, engineering problems involve a variety of contextual factors (existing infrastructure, governmental regulations) and stakeholders (clients, employers, end-users). Those complex factors are ultimately translated by engineers into sets of specifications, typically quantitative ones, that form the boundary conditions of the engineering problem. Once translated, inquiries into the context no longer need to be made and the methods of engineering can proceed (Bucciarelli 1994; Houkes 2008; Norman 2013; Vincenti 1990, ch. 3). For instance, an engineer who is designing a bicycle must attend to specifications that are sensitive to the social context in which bicycles are bought, sold, and used. However, the bicycle engineer does not need to grapple with the problem of how bicycles *should* be used in society; those problems are left to others (e.g., politicians, city planners). Rather, the engineer need only design bicycles that meet the specifications that are taken as "given."

Reductionism is often seen in the way that the STEM fields use mathematical modeling (Bucciarelli 2009; Cartwright et al. 1995; Cross 2000; Frigg and Hartmann 2019; Pitt 2013; Simon 1996). Mathematical modeling is powerful because when complex systems can be represented in entirely mathematical terms, then the analytical tools of mathematics can be fully brought to bear on the situation. It is, however, a reductive process because all problems will include aspects that are not easily put into mathematical terms; those aspects will need to be either ignored or distorted in order to use the model (Cartwright 1983). An illustrative example is cost-risk-benefit analysis, wherein the consequences of a new or proposed technology are evaluated using a mathematical model where all possible costs and benefits are represented as monetary amounts weighted by probabilities (Fischhoff 2015). However, many costs are difficult to put into monetary terms, such as the death of a human being, or an animal, or even an entire species (Shrader-Frechette 1987).

In sum, STEM problems are reductive because the STEM fields are not equipped to directly address certain dimensions of complex problems (e.g., the social, cultural, political, ethical dimensions). At most, those dimensions are relegated to the background and transformed into context-specific boundary conditions that are comprehensible to the STEM fields. The reductive aspect is a critical difference between Pure STEM and STEM-Relevant problems in that the latter class of problems retains those broader dimensions.

3 Implications for STEM Education

Equipped with an understanding of the nature of STEM problems, I now turn to the question of how that understanding can be brought to bear on STEM education efforts. Many proponents of STEM education, particularly those who support STEM integration, argue that teachers ought to engage their students in STEM problem-solving in the classroom (Bryan et al. 2016; Guzey et al. 2016; Johnson 2013; Kelley and Knowles 2016; OECD 2017; Stohlmann et al. 2012; Tytler et al. 2019). In line with that perspective, instructional approaches to integrated STEM education are emerging, and curriculum materials that bear the "STEM" label are beginning to proliferate. The ideas put forth in the preceding sections allow those approaches and materials to be critically examined, particularly in relation to the kinds of problems that are present.

A comprehensive review of STEM curricula is beyond the scope of this paper. Instead, I will examine two approaches that have considerable currency within contemporary educational reform efforts. I first focus on an instructional approach that is oriented toward Pure STEM problems, then examine an alternative approach that emphasizes STEM-Relevant problems. Those approaches certainly do not exhaust the possibilities, but they do serve to highlight crucial differences and tensions that exist. In the final section, I turn to the question of how to prepare teachers who are sufficiently knowledgeable about the nature of STEM problems to navigate the murky terrain of STEM curricula.

3.1 A Pure STEM Approach

One instructional approach with a growing amount of interest is the use of engineering design-based STEM instruction. In this instructional model, students are presented with an engineering problem, typically one in which students will need to design a technology that will require students to learn and/or use relevant science and mathematics concepts (English 2017; Stohlmann et al. 2012). Although centered on engineering design, the approach is presented as an example of STEM integration because the design problem raises scientific and mathematical questions for students alongside engineering ones (Kelley and Knowles 2016). Of course, not all engineering design problems will necessarily connect to science and mathematics problems, and educators should scrutinize engineering design tasks to determine whether they are STEM problems or strictly engineering ones. A wide array of engineering design problems can be found in published curriculum and in the educational literature; some representative examples are given in Table 3.

The examples in Table 3, and the engineering design approach more generally, emphasize *Pure* STEM problems according to the typology presented in Section 2.2.1. In some cases, attention is given to social aspects of the design problems. For instance, several of the design problems reference a user, a client, or other stakeholder. However, those considerations are not foregrounded and simply form the context for the problem otherwise Pure STEM problem-solving activity. Of course, engineering-focused STEM instruction *could* be more attentive to the non-STEM dimensions of a situation. For instance, the sequence of lessons described by Ewalt et al. (2015) engages students in thinking about how a landfill site in a community can be most effectively put to use. While those lessons ultimately emphasize the various STEM aspects of the problem, they also include attention to non-STEM dimensions, such as inquiries into the values of the community and what kinds of spaces the community would prefer.

Table 3 Examples of engineering design problems in published curricula and literature

Source	Examples
Cook et al. (2015)	Design a prosthetic hand for a student who cannot type
Ewalt et al. (2015)	Design a way to use an old landfill site so that it is not infested by seagulls
Hobbs et al. (2019)	Design a Rube Goldberg machine to complete a simple task Design a water rocket that will travel as far as possible Design a model car that will move as fast as possible Design a bridge
Moore and Tank (2014)	Design a habitat for a hamster Design an organizer for a toy box
Museum of Science, Boston (2007)	Design a method for cleaning oil out of water Design a solar oven that achieves the highest temperature Design a package that can keep a plant healthy
Siverling et al. (2019)	Design a cooler to be used by fishermen to keep fish cold Design a method to extract maximum DNA from strawberries Design tools for reducing runoff Design a “survival suit” for different environments (desert, tundra, etc.)

As noted previously, an interesting facet of the discourse around STEM education is that the kinds of problems that are typically invoked as motivating STEM (e.g., Caprile et al. 2015; Holdren et al. 2013; NRC 2014) are broader than the predominantly Pure STEM problems listed in Table 3. Along similar lines, the engineering design-based approach tends to be somewhat distant from "real-world" problems in that most problems in the real world are not ones of engineering design (although some certainly are). However, the advantage of the engineering design-based approach is that, by focusing on narrower problems with fewer dimensions, emphasis can be placed on learning content within the STEM fields. That, of course, is true only so long as the engineering problems genuinely raise scientific and mathematical problems as well, which does not always occur in instructional practice (Berland et al. 2014; Chase et al. 2019; King and English 2016). Helping students learn STEM concepts and practices in the context of engineering design is certainly valuable, but a serious question that needs to be addressed is the extent to which this approach to STEM integration aligns with the broader goals of STEM education. Engaging in engineering-focused Pure STEM problems will not necessarily prepare students for the kinds of complex problems they will encounter in the world, given that most of those problems cannot, and should not, be addressed solely by means of designing new technologies. A broader approach to STEM education would seem to be required.

3.2 A STEM-Relevant Approach

Alternative instructional approaches exist that seek to engage students in problems that retain the non-STEM dimensions of problems encountered in the real world. By using complex real-world problems as points of entry, those approaches seek to engage students in STEM-Relevant problems rather than Pure STEM problems. Foregrounding complex real-world problems has a long educational history. It has roots in the work of Dewey (1938) and the progressive movement in the early twentieth century, which emphasized the importance of learning for engagement with focal real-world problems (DeBoer 1991). Within science education, the Science-Technology-Society (STS) movement of the 1980s sought to draw attention to the interactions between science and important societal issues (DeBoer 1991; Yager 1996). A more recent movement within science education is the framework of socioscientific issues (SSI; Zeidler et al. 2005), in which students reason about complex problems that have scientific, social, cultural, and moral/ethical components. Those non-science components are regarded as essential aspects of SSIs (Sadler 2011; Zeidler 2014). The focus of SSI scholarship is on science education, but an examination of specific SSIs reveals that many (though not necessarily all) include dimensions related to technology, engineering, and mathematics. Table 4 provides some illustrative examples of SSIs which could be framed as STEM-Relevant problems.

Proponents of SSIs do not generally regard the SSI framework as aligned with integrated STEM. Zeidler (2016), for instance, places the SSI framework in opposition to the current STEM movement. However, the opposition described by Zeidler might be due to a current overemphasis on Pure STEM problems within instruction that bears the "STEM" label. Pure STEM problems necessarily ignore much of the sociocultural complexity of the real world, and in Zeidler's view, SSI reframes "STEM learning within broader sociocultural and related political contexts of the needs and concerns of the larger global society" (p. 19). That is, SSI returns the context that the reductive nature of Pure STEM problems removes; in that respect, SSIs are congruent with STEM-*Relevant* problems.

Table 4 Examples of SSIs that can be regarded as STEM-Relevant problems

Source	Examples
Sadler and Zeidler (2005)	Should gene therapy be used to eliminate Huntington's Disease from developing embryos? What about correcting nearsightedness?
	Should cloning be permissible as a reproductive option? What about for the production of transplantable organs?
Kolstø (2006)	Risks and benefits of the construction of new power lines
Fowler et al. (2009)	Issues related to the use of stem cell research and the treatment of disease
	Questions of animal rights in the context of pharmaceutical testing and medical research
	Risks and benefits in the use of vaccines for prevention of disease
Dawson and Venville (2010)	Should a genetically modified tomato be grown and sold?
	How should genetic counselors handle situations where the paternity of a fetus is in doubt?

The advantage of the SSI approach is therefore that the problems under study are much more proximal to those that students might encounter in the real world. If the purpose of STEM education is to prepare students to engage with the kinds of problems described by policy documents (e.g., Caprile et al. 2015; Holdren et al. 2013; NRC 2014), which are by large STEM-Relevant problems rather than Pure STEM problems, then the SSI approach is attractive. Equally important is that, by including overt emphasis on the non-STEM dimensions of complex problems in the world, the SSI approach more clearly acknowledges the vital contributions of non-STEM fields. The emphasis on STEM has the potential to give students the wrong impression that the STEM fields are all that are needed to solve the many serious problems that exist in the world. While the STEM fields clearly have roles to play, the notion that they are sufficient is deeply misguided. The inclusive character of SSIs avoids promoting that erroneous view. However, a potential drawback of the SSI approach is that, if care is not taken, the STEM dimensions of the complex problems can come be overlooked by students, which would be problematic for the STEM classroom setting (Zeidler 2014).

The perceived opposition between SSI and STEM is indicative of a deeper tension. Should students engage with problems that are narrowly constructed to be Pure STEM problems, or should they engage with more complex STEM-Relevant problems? That tension echoes one that exists between competing visions of science literacy, which Roberts and Bybee (2014) label Vision I and Vision II. Vision I of science literacy is similar to Pure STEM in that its view of literacy is focused "within science – general familiarity and fluency within the discipline" (p. 546) and is focused primarily on preparing students to address strictly scientific problems. In contrast, Vision II emphasizes the learning of science such that students can engage with complex issues that "include political, economic, and ethical considerations" (p. 546). In other words, Vision II is aligned with STEM-Relevant problems. Roberts and Bybee worry that there has generally been a retreat from Vision II toward Vision I over the past decade. That trend is largely consistent with contemporary currents in STEM education in that the emphasis appears to be on Pure STEM problems that place engineering design tasks in the foreground. But given that the discourse surrounding the importance of STEM education often invokes problems that include social, political, and other non-STEM dimensions, the emphasis on Pure STEM is a potentially problematic trend.

4 An Analytical Tool

For teachers seeking to engage students in STEM problem-solving, there are no shortage of curriculum resources that bear the "STEM" label, some of which are consistent with the approaches described above, but many of which are not. To effectively use those resources, teachers need conceptual tools to evaluate them and modify them for their own unique classroom environments. A teacher should be able to determine whether a STEM activity focuses on a non-STEM, Pure STEM, or STEM-Relevant problem, and whether that type of problem makes sense given the teacher's instructional goals. Teachers therefore need an understanding of STEM problems as well as the nature of problems in the individual STEM fields. In addition, teachers who are informed about the nature of STEM will be better able to communicate to students the nature of the problems under investigation in the classroom. If students are engaged in purely scientific, mathematical, or engineering problems, there is little reason to use the "STEM" label. At best, labeling all problems from those fields as "STEM" is confusing to students, who would benefit from knowing how disciplines such as science, mathematics, and engineering differ from one another (Pleasants and Olson 2019; Pleasants et al. 2019). At worst, doing so promotes misunderstandings and conflations among the STEM fields.

The representation of different STEM problem types in Fig. 1 can serve as a useful starting point for teachers, but a more targeted framework is useful for assessing the extent to which a given problem represents a STEM problem (and which type it represents). Figure 2 gives such an analytical framework; the questions included within each of the categories in Fig. 2 call attention to the extent to which the problem in question shows the characteristics of STEM problems, and the final category addresses whether the problem is Pure STEM or STEM-Relevant.

To illustrate how the framework in Fig. 2 can be applied to instructional decision-making, what follows is a classroom example in which the same issue is framed alternatively as a non-STEM, Pure STEM, or STEM-Relevant problem.

4.1 Context

A middle-grade science teacher is currently planning a unit in which students will learn concepts related to the water cycle, erosion, and flooding. The community in which the teacher and students live is near a large river which has recently experienced several major flood events that have damaged local homes and businesses. The teacher thinks that this will be an interesting issue for students, but needs to decide how the issue will be framed. The three options below illustrate how the problem can be presented to and investigated by students as a non-STEM, Pure STEM, and STEM-Relevant problem. After each description is an explanation for its categorization.

4.2 Option 1: Non-STEM Version

Students are shown videos and pictures of the levees that are in their local community as well as other nearby towns and cities. Students are then tasked with designing a model levee that would be effective in preventing flooding. They are given an array of materials that they might use for the levee, the costs of those materials, and the conditions under which their model levee will be tested. Students spend time designing, building, and testing their levee models, then redesigning and revising their models to make them more effective at completing the task.

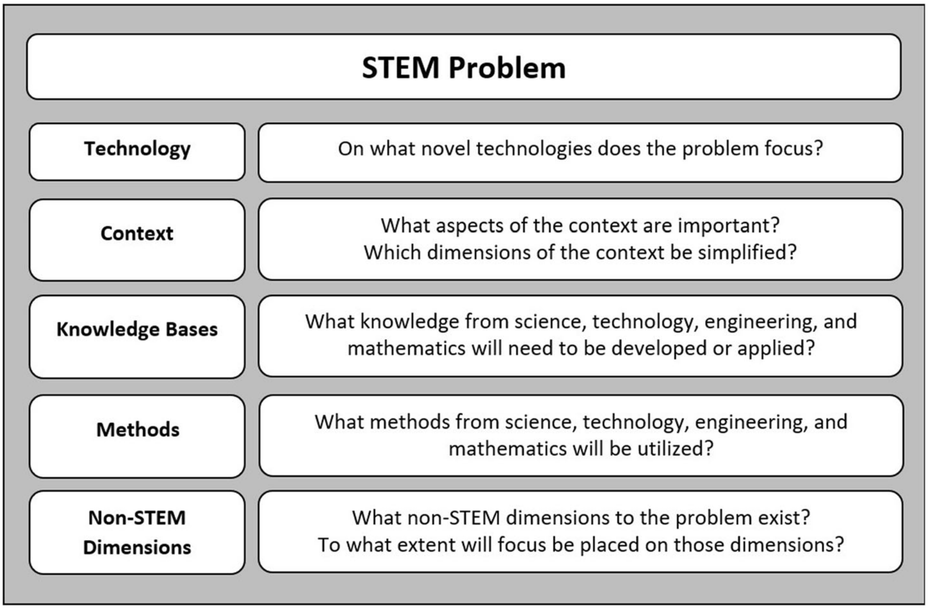

Fig. 2 An analytical framework for STEM problems

Students ultimately submit a design plan for their levee and an explanation of why they think it is effective.

[This is a non-STEM problem because, while there is a technological problem being investigated, and while that problem has been placed to some extent in context, there are no clear scientific or mathematical problems being raised because the knowledge bases and methods of those fields are absent. Moreover, it is unclear whether this is a genuine case of engineering design or simply tinkering with materials.]

4.3 Option 2: Pure STEM Version

Students are shown videos and pictures of the levees that are in their local community as well as other nearby towns and cities. The teacher points out that in the past few years, the levees have not effectively prevented their local community from flooding, and tasks students with determining what changes need to be made to the levees to ensure that future floods will be prevented. The teacher points out while it might be tempting to just make the levees as large as possible, doing that will come at considerable cost. The better approach will be to make the levees just large enough to create a very low risk of future flooding. This raises scientific questions about the flooding patterns of the local river, because understanding those patterns is crucial to making decisions about levees. Students investigate why the river floods in the first place and also access historical data sets about the water levels in the river. They use mathematical tools to analyze those data and estimate what the highest water levels are likely to be in the future. They then ultimately create a report that describes a design for an improved levee system.

[This version can provide clear answers to all of the questions in the first four categories of Fig. 2*. There is a clear technological problem that has been placed in a specific context. There are specific scientific, mathematical, and engineering problems that have been raised. There is*

also a clear reductionist approach in that the problem has been cast entirely in terms of how large the levee ought to be. The non-STEM dimensions are not being considered, which makes it a case of Pure STEM.]

4.4 Option 3: STEM-Relevant Version

Students are presented with information about what the impacts of local floods have been on their community, and then presented with the question: what should their community do to address the impacts of floods? A question that quickly arises, and that students investigate, is why floods occur in the first place. They learn about what kinds of floods are typical in different time frames by analyzing historical data sets. They then examine some of the technological methods that the community currently uses to control floods. They also examine how the community addresses the impacts of the floods that do occur. They look at how homes and businesses are insured by floods and how the local and state government provide assistance to impacted individuals. Students also consider how certain parts of the community are more prone to flooding than others, and how the local government determines which areas should or should not be used for building. After learning about the wide array of strategies that their community uses to cope with flooding, students are asked to consider whether the current set of strategies makes sense, or whether changes need to be made. They consider who bears the costs for different parts of the strategy (e.g., the local government or individuals), and argue about who *should* bear those costs. In the end, they produce a flood plan for their community that reflects their thinking about the full range of issues they explored.

[This version makes clear the scientific, technological, engineering, and mathematical problems that are present as well as Option 2. It also includes, however, specific attention to the non-STEM components of the broader problem. It does not ignore the social, political, and economic dimensions of the problem, positioning it as a STEM-Relevant problem.]

5 Next Steps

Empirical research will be needed to determine the extent to which the framework in Fig. 2 is assistive for teachers who are designing STEM instruction. In addition, empirical work should examine the different educational outcomes promoted by Pure STEM versus STEM-Relevant problems used during instruction. Several pertinent questions are:

1) To what extent, if any, does the framework in Fig. 2 help teachers analyze existing curriculum resources and modify those resources to be consistent with their goals and objectives?
2) To what extent, if any, does the framework in Fig. 2 help teachers implement STEM instruction that is consistent with the teachers' goals and objectives?
3) What learning goals are more effectively promoted using Pure STEM problems in the classroom, and which are more effectively promoted using STEM-Relevant problems? To what extent would students benefit from engaging in both kinds of problems?

An ambitious and important objective of STEM education is to prepare students for personally and societally relevant problems that they are likely to encounter in a world that is deeply influenced by STEM fields. That being the case, the STEM education community must seek greater clarity around the nature of those problems as well as the kinds of problems that students ought to encounter during STEM instruction. The present work is a first step toward that clarity, but much more work needs to be done to prepare STEM teachers who can promote the lofty goals of STEM education.

Conflict of interest The author declares no conflict of interest.

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