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RESEARCH REVIEW

Promoting STEM Literacy in K-12: A Position Statement

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Abstract

Despite international enthusiasm for STEM education, currently there are no commonly agreed upon goals of STEM education. STEM education research and practice would benefit from a common conceptualization of the goals and outcomes of STEM education. This conceptualization could guide the coordinated development of STEM curriculum, instruction, and assessment and facilitate research and communication on the systematic development and evaluation of STEM education from elementary through high school and beyond. Based on a systematic literature review, in this position paper, we propose that STEM literacy be used to conceptualize STEM education goals and outcomes. STEM literacy can be defined as a capacity for using multidisciplinary knowledge of science, technology, engineering, mathematics as well as others to solve real-world problems, forming a STEM identity, and demonstrating an understanding of how STEM works. Specifically, STEM literacy comprises three dimensions: (1) acquiring and applying science, technology, engineering, and mathematics to solve real world problems; (2) possessing a STEM identity; and (3) understanding how STEM works. Beyond the above competences, integrated STEM literacy is systems thinking, collective participation, and equitable and inclusive. We end this position paper by calling for a research agenda on STEM literacy.

Originating from the US National Science Foundation in the early 1990s (Koehler, Binns & Bloom, 2021), STEM (Science, Technology, Engineering, and Mathematics) education has been adopted in Asia (Li et al., 2020), Australia (Ellis & Williams, 2020), Latin America (Bascopé et al., 2020), and Europe (European Schoolnet, 2018; Morgan & Kirby, 2016) as well as North America (Alianza para la Promoción de STEM, 2019; National Research Council, 2014; Let's Talk Science, 2017). There is a growing body of literature on STEM education research (e.g., Anderson & Li, 2020; Johnson, Mohr-Schroeder, Moore & English, 2020; Liu & Wang, 2023), and curriculum materials for implementing STEM education in K-12 are also being developed (e.g., NextGenScience, 2025).

In the US, there are at least three main reasons for the promotion of STEM education (NRC, 2014): (a) the persistent underachievement of K-12 students in disciplinary learning of mathematics and science; (b) the increasing demand for the STEM workforce, and (c) the persistent disparity among major ethnic groups in learning, particularly in mathematics and science (Koebler, Binns & Bloom, 2021; Johnson et al., 2020; NRC, 2014). Also, engineering historically had not been commonly offered in K-12 schools. However, engineering and technology design are a natural integrator of STEM disciplines, affording students opportunities to learn to apply scientific and mathematical concepts in practical, real-world contexts, making these subjects more engaging and relevant for students. In addition, STEM education intends to address the often-overlooked aspect of affect in science education (Fortus, Lin, Neumann & Sadler, 2022).

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Conceptions of STEM Education

While there have been various conceptions of STEM education (Bryan & Guzey, 2020; Bybee, 2013), the emerging scholarship converges on the interdisciplinary teaching and learning of science, technology, engineering and mathematics, i.e., integrated STEM (e.g., Anderson & Li, 2020; NRC, 2014). Specifically, researchers have identified essential characteristics of integrated STEM education, such as employing engineering/engineering design as a meaningful integrator of STEM content, justifying design decisions through the use of scientific and mathematical concepts, focusing on an authentic issues or real-world problems, engaging in engineering design, and developing 21 st century skills (Bryan, Moore, Johnson, & Roehrig, 2015; Roehrig, Dare, Ellis & Ring-Whalen, 2021; Moore et al.,2021). The *STEM Road Map* explicitly applies the essential characteristics of integrated STEM to outline a progression of STEM learning from elementary through high school (Johnson et al., 2021). Moreover, NextGenScience (2025) provides a suite of tools to assist educators in designing integrated STEM instruction. For example, they offer a searchable repository of vetted, high quality integrated STEM units that align with the NGSS (see https://www.nextgenscience.org/resources/examples-quality-ngss-design). Many other countries such as Australia, Canada, China, Finland, Ireland and Israel, have also been actively developing integrated STEM curriculum materials and assessments (Liu & Wang, 2023). The above efforts demonstrate the intended conception of STEM (or more clearly "integrated STEM") to be the explicit, intentional integration of core disciplinary content and practices of STEM disciplines.

Goals of STEM Education

Despite international enthusiasm for STEM education, currently there are no commonly agreed upon goals of STEM education. An NRC committee (2014) identified *goals* of STEM education to include STEM literacy, 21 st century competencies, STEM workforce readiness, interest and engagement, and making connections. The committee also identified *outcomes* of STEM education to include learning and achievement, 21 st century competencies, STEM course taking, educational persistence, graduation rates, STEM-related employment, STEM interest, development of STEM identity, and the ability to make connections among STEM disciplines (NRC, 2015). The *STEM Road Map* derived learning outcomes of STEM modules based on learning expectations defined by the individual disciplinary standards of science, technology, engineering and mathematics (Johnson et al., 2021). There are currently diverse goals and outcomes of STEM education. The variety of STEM education goals and outcomes is inevitable because, unlike science and mathematics that are core K-12 school subjects, STEM education is not a school subject, although some schools may offer specific STEM courses as electives. STEM education is better considered as an ecosystem that spans inside and outside classrooms, formal and informal education (NRC, 2015). STEM education research and practice would benefit from a common conceptualization of the goals and outcomes of STEM education. This conceptualization could guide the coordinated development of STEM curriculum, instruction, and assessment. A common conceptualization could also facilitate research and communication on the systematic development and evaluation of STEM education from elementary through high school and beyond.

We believe *STEM literacy* is a powerful construct that can be used to conceptualize goals and outcomes of STEM education, and there is a general agreement in the literature that STEM literacy is a desirable goal of STEM education (Falloon et al., 2020; Zollman, 2012) For example, one common goal identified for K-12 STEM education is the promotion of STEM literacy (Bybee, 2010). Also, one of the three goals identified in the *US Federal Five-year Strategic Plan for STEM Education* (Committee on STEM Education, 2018) is building a strong foundation for STEM literacy. However, although many definitions of STEM literacy have been proposed (e.g., Balka, 2011; Bybee, 2010; Cavalcanti, 2017; Falloon et al., 2020; Jackson & Mohr-Schroeder, 2018; Jackson et al., 2021; Mohr-Schroeder et al., 2015; National Governors Association, 2007; National Research Council, 2011; Tang & Williams, 2019; Tenney et al., 2023; Zollman, 2012), a commonly agreed upon definition of STEM literacy remains elusive. Synthesizing the variety of definitions of STEM literacy, Mohr-Schroeder et al. (2020) offered a dynamic, process, equitable, and content-oriented definition of STEM literacy as follows:

> *STEM literacy is the dynamic process and ability to apply, question, collaborate, appreciate, engage, persist, and understand the utility of STEM concepts and skills to provide solutions for STEM-related personal, societal, and global challenges that cannot be solved using a single discipline (p. 33).*

The Need for a Common Framework of STEM Literacy Outcomes

While a general definition of STEM literacy as the goal of STEM education is useful, what is important for the implementation of STEM education, i.e., curriculum, instruction and assessment, is the operationalization of STEM literacy into learning outcomes. This is because curriculum and instructional designs require explicit and operational statements of what students are expected to achieve (Tyler, 1949; Wiggins & McTighe, 2005). Measurement of STEM literacy also requires articulation of the attributes of students who are STEM literate (Liu, 2020). For individual STEM disciplinary literacies of science, mathematics, technology and engineering, there are curriculum standards that define what students are expected to know and to do at different grade levels (e.g., International Technology Education Association, 2007; National Governors Association, 2000; NGSS Lead States, 2013). Large-scale international comparison studies of mathematics and science achievements also provide operationalization of mathematics and science literacies (e.g., OECD, 2023; Mullis et al., 2021). Curriculum standards and assessment frameworks, such as the preceding examples, provide guidance for curriculum material developers, K-12 teachers and assessment developers; they also act as common frameworks for research communication and knowledge accumulation.

Absent of a common framework for STEM literacy, formal and informal STEM education in K-12 is currently in a state of diffusion. For example, a teacher may design a STEM unit on renewable energy with the main learning objectives of developing student conceptual understanding of energy transfer, while another teacher may design a similar STEM unit with the main learning objectives of developing student problem-solving skills and future STEM career interests. While different curriculum and instruction units can have different student learning objectives, without a common framework, systematic implementation of STEM education across K-12 is difficult, and cross-sectional and longitudinal comparison of student STEM learning outcomes becomes almost impossible. Coordination between disciplinary STEM education (e.g., science education, mathematics education, engineering education, and technology education) and integrated STEM education, and between formal and informal STEM education may also be hindered. For example, a STEM education researcher may develop a STEM literacy measurement instrument with the focus on student conceptual understanding of disciplinary ideas of science, technology, engineering and mathematics, while another researcher may also develop a STEM literacy measurement instrument with the focus on students' interdisciplinary problem-solving, STEM self-efficacy, and career interests. The above situation is called "Jingle and Jangle Problems." A Jingle problem occurs when measures that go by the same name actually refer to different constructs so that measurement results do not correlate; a "Jangle Problem" occurs when measures that go by different names refer to the same construct and thus are highly correlated (NRC, 2022). Lack of a common framework hinders the development of STEM education as a scholarly field because as knowledge is generated by different studies, it becomes unclear if and how it can be compared, integrated, and strengthened.

The purpose of this paper is to propose a set of student learning outcomes to facilitate consensus-building around the conceptualization of STEM literacy. We agree with Zollman (2012) that STEM literacy should go beyond literacies of individual STEM disciplines, "where the total is much more the sum of the individual parts" (p. 15). The authors of this position paper are STEM education researchers from four countries (China, Israel, UK, and USA). Each of them has more than three decades of STEM teaching and research experiences, published widely in major STEM education journals, and served in various leadership roles in major international STEM education associations (e.g., NARST – a worldwide organization for promoting science teaching and learning through research; European Science Education Research Association). Further, an international symposium on STEM literacy was held in February 2025 to University of Macau. During and after the symposium, the group engaged in discussions and deliberations on student learning outcomes of STEM literacy. While not claiming to represent the STEM education community, we collectively assert the following student competence statements to promote scholarly exchange so that a common conceptualization about STEM literacy may emerge. A common conceptualization does not necessarily mean that there should be only one perspective on STEM literacy; building consensus while valuing the diversity and pluralism of ideas is a hallmark of any academic discipline.

In order to generate the STEM literacy statements of student learning outcomes, we first conducted a systematic search of Web of Science, ERIC, ProQuest, and Google Scholar using the terms of "STEM literacy" and "STEAM literacy". We included the term STEAM because in many countries, such as South Korea, STEAM is preferred instead of STEM (Li et al., 2020). A total of 740 documents were identified. After removing duplicate records, we retained 602 documents. A review of titles and abstracts for relevance to K-12 integrated STEM education resulted in 306 documents, and a follow-up full-text review for specific definitions and student competence statements of STEM literacy resulted in a final set of 37 documents; the other documents do not contain a definition or explicit statement of student STEM learning outcomes. These 37 documents included journal articles, conference proceedings, dissertations, and reports; they included not only definitions of STEM literacy, but also elaborations on student competences of STEM literacy. Based on these definitions and competences of STEM literacy, we created a list of STEM literacy competences (see the Appendix). For example, Tucker-Raymond et al. (2016) proposed a STEM literacy to include the following practices: posing and solving problems in the world and in the design process; identifying, organizing, and integrating information across sources; creating representational forms and traversing representational systems and materials; communicating information in new ways to different audiences; and documenting making processes and/or milestones (p. 3). Accordingly, we derived the following student competence statements:

1. STEM literacy includes posing and solving problems in the world and in the design process;
2. STEM literacy includes identifying, organizing, and integrating information across sources;
3. STEM literacy includes creating representational forms and traversing representational systems and materials;
4. STEM literacy includes communicating information in new ways to different audiences.

The authors of this position paper independently rated each of the statements as "Agree" or "Don't Agree" or provided comments to the statements that indicated partial agreement. The statements on which all the authors agreed or partially agreed were used as the basis for our position statements. Conceptually similar statements were then combined and the statements were rephrased as student competences using a consistent format of starting with an action verb. For example, Peterson (2017) defines a STEM-literate student to be able to "demonstrates problem-framing and problem-solving skills, applying them across disciplines" (p. 23). Cuso (2020) defines STEM-literacy to "be able to identify and apply core ideas and the ways of thinking, doing, talking and feeling of Science, Engineering and Mathematics in a relevant integrated way, so that we can both understand, make decisions and/or act in front of complex problems and build creative solutions, using the necessary technologies in a collaborative way." (p. 22) Huang et al. (2024) includes in their STEM literacy framework the ability to solving problems (p. 871). We combined and rephrased these and other conceptually similar and related statements as the following statement: Apply science, technology, engineering, and mathematics to solve complex problems.

Finally, we grouped the statements into three categories based on their conceptual connections and our knowledge of the STEM education literature. These statements are high-level competence statements that, should they be accepted by the community, will require further elaboration and validation. The three categories involve Zollman's (2012) three domains of STEM literacy: cognitive, affective, and psychomotor learning domains; they also generally agree with Falloon et al.'s (2020) four dimensions of STEM literacy: developing STEM disciplinary knowledge, engaging constructively with STEM issues, understanding STEM endeavor, and understanding how STEM shapes our world. The following position statement summarizes the resulting consensus about STEM literacy among the authors.

Position Statement

STEM literacy is a capacity for using multidisciplinary knowledge of science, technology, engineering, mathematics as well as others to solve real-world problems, forming a STEM identity, and demonstrating an understanding of how STEM works.

Competences of STEM Literacy

Dimension 1: A STEM literate person is able to acquire and apply science, technology, engineering, and mathematics to solve real world problems:

Competence 1.1 Possess knowledge and understanding of science, technology, engineering and mathematics concepts and practices (Donmez, 2020; Huang et al., 2024; NRC, 2011; Wu et al., 2024);

Competence 1.2 Construct new science, technology, engineering, and mathematics knowledge (Abdullah Al-Jubouri et al., 2021; Bybee, 2010; Falloon et al., 2020; Kenedi et al., 2023; Techakosit & Nilsook, 2018; Wannapiroon et al., 2021; Zollman, 2012);

Competence 1.3 Use science, technology, engineering and mathematics knowledge to develop questions and identify STEM-related issues or problems (Braund, 2021; Bybee, 2010; Couso, 2020; Kenedi et al., 2023; Persaud-Sharma, 2013; Techakosit et al., 2018; Tucker-Raymond et al., 2016; Wannapiroon et al., 2021);

Competence 1.4 Apply science, technology, engineering, and mathematics knowledge and practice to solve complex problems (Balka, 2011; Couso, 2020; Donmez, 2020; Huang et al., 2024; Jackson et al., 2021; Jackson & Mohr-Schroeder, 2018; Kenedi et al., 2023; Mohr-Schroeder et al., 2020; Rahmadani et al., 2023; Techakosit et al., 2018; Tucker-Raymond et al., 2016; Wannapiroon et al., 2021; Zaky, 2024).

Competence 1.5 Apply 21st century skills (critical thinking, collaboration, creativity and communication) to solve real-world problems (Jackson et al., 2021).

Competence 1.6 Communicate STEM-related information to different audiences (Kenedi et al., 2023; Tucker-Raymond et al., 2016; Techakosit et al., 2018; Wannapiroon et al., 2021).

Competence 1.7 Make informed decisions about STEM-related issues using sound reasoning (Couso, 2020; Ezzeldin, 2022; Kamel, 2021; Peterson, 2017;

NRC, 2011; Techakosit et al., 2018; Wannapiroon et al., 2021).

Dimension 2: A STEM literate person possesses a STEM identity (Jackson et al., 2021; Zollman, 2012):

Competence 2.1 Engage with STEM-related issues, knowledge, and information as concerned, affective, and constructive citizens (Braund, 2021; Bybee, 2010; Ezzeldin et al., 2022; NRC, 2011; Jackson et al., 2021).
Competence 2.2 Show a positive STEM disposition (i.e., curiosity, enthusiasm, perseverance, initiative, collaboration, creativity, attitudes) (Donmez, 2020; Jackson et al., 2021; Wu et al., 2024).
Competence 2.3 Demonstrate a motivation to learn about STEM (Donmez, 2020).

Dimension 3: A STEM literate person understands how STEM works (Donmez, 2020):

Competence 3.1 Understand the characteristic features of STEM disciplines as forms of human as well as epistemic and cognitive endeavor (Bybee, 2010; Falloon et al., 2020);
Competence 3.2 Recognize how STEM disciplines shape our material, intellectual, and cultural world (Bybee, 2010; Cavalcanti, 2017; Falloon et al., 2020; Kamel, 2021).

Beyond Competences

Statements about student competences can be considered in terms of domain-general and domain-specific features of STEM. In other words, particular aspects such as "motivation to learn" and "21st century skills" can be considered in the context of broad skills. However, when situated within STEM contexts, they gain domain-specificity given the examples of their application will be anchored in disciplinary practices of STEM. Hence, the competences presented above are specific to STEM education; considered as a whole, they present a new vision of STEM literate person for the 21 st century. This new vision builds on current disciplinary literacies in science, technology, engineering, mathematics and others, and goes further to emphasize solving real-world problems, building an identity and developing an appreciation of STEM as a social-cultural-political activity.

The competences listed above, although essential, should not function independently; a fully STEM literate person is able to integrate the competences in solving real-world problems, forming a STEM identity, and understanding how STEM works. The capacity to integrate the competences is a higher level of STEM literacy; it is the ultimate goal of STEM education. There are three characteristics of this integrative STEM literacy.

First, integrative STEM literacy is characterized by systems thinking (English, 2023). Systems thinking is an approach to solving complex problems from a perspective of the system and its interacting components; it is a holistic mindset to identify causes and effective and sustainable solutions. Humankind is facing many grand challenges, such as global health, food security, environmental sustainability, and so on. Solving these challenges requires simultaneously considering many possible causes and effects. Systems thinking consists of three elements: system elements, interconnections between and among elements, and system functions or purposes (Arnold & Wade, 2015). A STEM literate person is able to use the above defined competences to identify system elements, their interactions and system functions, and propose and test best solutions for systems to transform and sustain.

Second, integrative STEM literacy is collective. Real world problems are complex, to solve them requires many types of expertise. Given that expertise is distributed among individuals, in community, and geographical space, STEM literacy exists at both individual and group levels. Therefore, an integrative STEM literate person should be able to engage with others in community and at different levels of locality (i.e., local, regional, national, and international) in solving complex problems. Through active engagement, individuals use not only individual STEM competences but also take social and political actions. In this sense, integrative STEM literacy is collective, emergent and constantly evolving.

Last but not the least, integrative STEM literacy is equitable and inclusive. While the STEM competences listed above are grounded in the current structures of the STEM enterprise, particularly in engineering, integrative STEM literacy can be emancipatory and transformative. That is, a STEM literate person makes uses of diverse ways of knowing; he/she claims the "rightful presence" in STEM (Calabrese-Barton &Tan, 2020). For example, in engineering design, integrative STEM literacy is demonstrated as a socio-technical literacy by thinking critically not only within but also about engineering. An integrative STEM literate person asks questions such as: Who does engineering and for whom? Who decides what counts as engineering? Who benefits from and who is impeded, constrained, or otherwise adversely affected by engineering? How do social, political, cultural and economic structures create our present? (McGowan & Bell, 2020). Therefore, a STEM literate person is not only an efficient problem-solver, communicator, and team member, but also a critical thinker about why the problem they are addressing occurs and what consequences a solution to the problem may have.

Figure 1 presents the structure of STEM literacy. From Fig. 1, we see that the three-dimensional competences

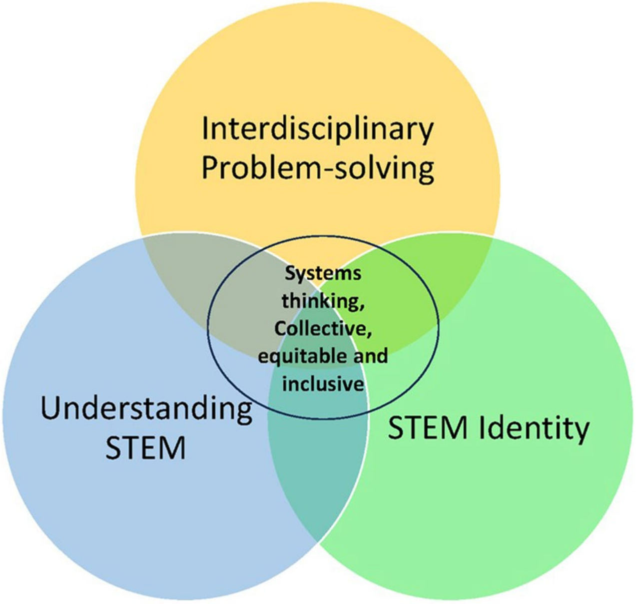

Fig. 1 Overlapping structure and the integrated and holistic nature of STEM literacy

overlap with each other; they also share characteristics of systems thinking, being collective, and being equitable and inclusive. Figure 1 highlights the integrated and holistic literacy.

Call for a Research Agenda on STEM Literacy

The proposed framework of STEM literacy competences is based on what current literature says and what we as a group believe to be essential for a person to be STEM literate. We are mindful that current literature on STEM literacy is diverse and there is no agreement on what a STEM literate person should possess or demonstrate. We also agree with Zollman (2012) that STEM literacy is an evolving deictic means for future learning. As an emerging and fruitful field of research, STEM literacy demands further conceptual and empirical inquires. For example, each of the three dimensions is tentative and requires further articulation and validation. Dimension 1 is about interdisciplinary problem-solving. While problem-solving in science and mathematics is an established field of research in science education and mathematics education (e.g., Gabel, 1994; Grouws, 1992), there is only a small body of literature on interdisciplinary problem-solving in STEM (e.g., Amalina & Vidakovich, 2022; Fang et al., 2023, Gao et al., 2020; Tan et al., 2023). However, there is increasing attention paid to engineering education as well as the role of artificial intelligence in STEM education (e.g., Usher & Barak, 2024). Dimension 2 is about STEM identity. There is a growing body of literature on science identity, math identity, as well as engineering identity and technology identity, but it remains unclear what is STEM identity and how it is distinct from other identities in science, mathematics, and so on (Tripp & Liu, 2026). As for Dimension 3, there is preliminary literature on the nature of STEM (Martínez-Martínez et al., 2025; Peters-Burton, 2014; and a special issue on the nature of STEM in *Science & Education* (Erduran, 2020). Future research will help articulate each of the dimensions, particularly in terms of the progression from kindergarten all the way through Grade 12, which will inform future STEM curriculum, instruction and assessment related to the dimensions. Finally, we do not necessarily consider the above competences to be comprehensive. Further research can validate these competences, revise and refine them, and add new competences deemed essential.

We emphasize that the identified competences should be approached holistically. Research has called for collective, critical, and transformative forms of literacies. For example, in science education, there is a call for collective and community science literacy (National Academies of Sciences, Engineering, and Medicine, 2016). There has also been emerging consensus for Vision III science literacy (Sjöström, 2024). That is, while Visions I and II science literacy emphasize science subject matter (knowledge, skills, disposition) and applications of science subject matter in solving problems (Roberts, 2007), Vision III science literacy calls for collective engagement (Liu, 2013), socio-scientific reasoning (Zeidler & Sadler, 2011), socio-political actions (Hodson, 2011), to name a few. Similarly, for STEM literacy, while individual STEM competences are important, they should not be considered in isolation, static, and context-free. Integrative STEM literacy emphasizes systems thinking, participatory action taking, and critical sociotechnical reasoning; it is consistent with some literacy visions proposed in the literature. For example, the worldly perspective of STEM literacy consists of the integrated knowledge dimension and the locality dimension (i.e., the connection between local and global contexts) (Rennie et al., 2020); and Jackson et al.'s (2021) equity-oriented STEM literacy is centered on disrupting systems of oppression and privilege by creating opportunity and access to high quality integrated STEM learning experiences for all learners. *How can STEM education provide equitable opportunities for all students to participate in communities of learners in an increasingly globalized world?* Therefore, STEM literacy should be considered as a layered construct comprising essential competences at its foundation and integrative STEM literacy at its apex. Much research is needed to fully understand the nature and structure of STEM literacy.

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Research Involving Human Participants and/or Animals Not applicable.

Informed Consent Not Applicable.

Consent to Participate Not applicable.

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