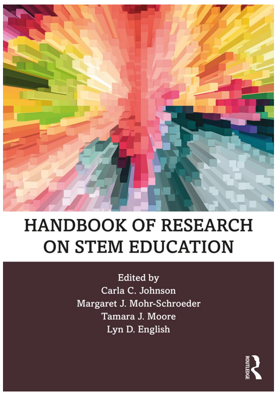

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MOVING TOWARD AN EQUITY-BASED APPROACH FOR STEM LITERACY

Margaret J. Mohr-Schroeder, Sarah B. Bush, Cathrine Maiorca and Megan Nickels

Introduction

> *The complexities of today's world require all people to be equipped with a new set of core knowledge and skills to solve difficult problems, gather and evaluate evidence, and make sense of information they receive from varied print and, increasingly, digital media.*
>
> *(U.S. Department of Education, 2016, p. i)*

An overarching goal of the reform efforts in STEM education, especially since 2013, has been to prepare a STEM-literate workforce; one that will bolster the social and economic well-being (e.g., Committee on STEM Education National Science and Technology Council, 2013; Kennedy & Odell, 2014; National Science Board, 2015) of countries across the world in STEM areas. However, groups historically underrepresented in STEM continue to be at risk of disengaging from STEM (e.g., Beasley & Fischer, 2012; Morgan, Farkas, Hillemeier, & Maczuga, 2016; Museus, Palmer, Davis, & Maramba, 2011). While many educators and educational researchers approach work with underrepresented students through a problem-solving framework to develop their positive STEM socio-academic identities, it is less common that attention to the cognitive-linguistic and affective dimensions of students' STEM transitions take center stage. In this chapter, we review the most recent decade of literature on STEM literacy, especially in, but not limited to, integrated STEM environments. We begin with a brief history of STEM literacy, then provide context and urge for consensus on a definition for STEM literacy, and finally, discuss characteristics of STEM literacy. The articles we reviewed with international perspectives were limited to STEM literacy as opposed to a siloed approach of mathematics, science, engineering, or technology literacy. In total, we reviewed 112 empirical studies, conceptual or research-informed practice-oriented articles, book chapters, syntheses, or reports published since 2009 that examined STEM literacy within an integrated STEM context. While there were many blog and news-media publications regarding STEM literacy, we chose not to include them so as to focus on research-based evidence of STEM literacy.

Integrated STEM, as defined by Moore and colleagues in Chapter 1 of this handbook, and Gutiérrez's (2008) four dimensions of equity—access, power, identity, and achievement—were our guiding analytical framework for the review. *Access* relates to what resources are available to participants (e.g., supplies, quality teaching, rigorous curriculum experiences). *Achievement* relates to student outcomes and the measurement of them. *Identity* not only relates to addressing students' pasts, but also balances the opportunities to self-reflect and to reflect with others as part of a learning experience. *Power* relates to social transformations at multiple points and levels (e.g., voice in the classroom, opportunity). All four dimensions are non-negotiable when truly embodying an equitable mindset. While a single, consensus definition of integrated STEM still does not exist, certain characteristics have been shown to be important in integrated STEM. These include (a) the need to address a complex, authentic, or real-world problem; (b) shared skills, practices, and concepts from across disciplines; (c) student-centered teaching strategies, including an emphasis on collaboration and teamwork; and (d) integration of at least two or more disciplines. Alongside the importance of integrated STEM is the opportunity and access to such educational opportunities (Flores, 2007). Equity must remain an integral and regular part of conversations to ensure each and every student experiences the distribution of power (Gutiérrez, 2008), especially as it relates to STEM literacy. We present findings from our review as a way to come to a shared understanding of what STEM literacy is, how it can be defined, and what it means to be STEM literate. For all students to become STEM literate, each and every student must have access to quality STEM learning experiences where STEM literacy is a focus. A clear understanding of what STEM literacy is and what it aims to do is necessary to design and implement integrated learning experiences.

History of STEM Literacy

In order to obtain a clearer understanding of STEM literacy, we need to first understand disciplinary literacies (e.g., Shanahan & Shanahan, 2012) as a definition and then examine the disciplinary literacies as they currently exist. Whereas literacy is the ability to read, write, spell, listen, and speak, disciplinary literacy refers to reading, writing, and communicating in the context of a given field (e.g., mathematics). In this section, we briefly discuss disciplinary literacies related to STEM, but in their individual contexts (i.e., science, technology, engineering, mathematics). The purpose is to understand the individual disciplinary literacies in order to build an understanding of how STEM literacy was derived.

Science Literacy

Historically, there are differing viewpoints on science literacy. One refers to how science is used in society, and the other refers to an individual's scientific knowledge (Holbrook & Rannikmae, 2008). The American Association for the Advancement of Science (AAAS, 1989) defined science literacy to include not only mathematics and technology but also the social and natural sciences. According to AAAS, a scientifically literate person understands that science, mathematics, and technology are interconnected human endeavors with both strengths and weaknesses. A scientifically literate person also has the thinking skills and scientific knowledge to use mathematics, science, and technology at both personal and societal levels. "Thus scientific, mathematical, and technological processes are important factors in improving society, along with thinking skills and scientific knowledge" (AAAS, 1989, p. 20). This definition reflects how science, technology, and mathematics are interconnected as well as the importance of being able to apply scientific knowledge and thinking. The National Research Council [NRC] (2012) defined science literacy as not only having scientific knowledge but being educated consumers of the technology and science which permeates everyday lives. The NRC also states that a scientifically literate person should appreciate the wonder and beauty of science and have the skills to continue to learn science outside of schools for either pleasure or a future career, regardless of the field. The NRC (2012) used this definition to develop the framework for the United States Next Generation Science Standards (NGSS Lead States, 2013) in which the science and engineering practices are introduced. These practices include:

1. Asking questions (for science) and defining problems (for engineering)
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics and computational thinking
6. Constructing explanations (for science) and designing solutions (for engineering)
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information

The Board on Science Education in the U.S. further refined science literacy to define aspects, including:

- an understanding of scientific practices;
- content knowledge (knowledge of basic facts, concepts, and vocabulary); and
- an understanding of science as a social process (National Academies of Sciences, Engineering, and Medicine, 2016).

It is important for individuals to be scientifically literate for economic, personal, democratic, and cultural reasons (National Academies of Sciences, Engineering, and Medicine, 2016). Economically, scientifically literate people can participate in society by pursuing either science-related jobs or jobs that require some scientific knowledge. Personally, an understanding of science helps individuals make knowledgeable decisions and actions that will lead to healthier and richer lives. Democratically, scientifically literate people are informed members of a democratic society that can participate in government decision-making that will impact problems that humanity faces. Culturally, "the sciences are important cultural activities that offer a powerful way to understand the world" (National Academies of Sciences, Engineering, and Medicine, 2016, p. 26). Science and technology shape the ever-changing world around us.

Technology Literacy

Technology refers to "the act of making or crafting, but more generally it refers to the diverse collection of processes and knowledge that people use to extend human abilities and to satisfy human needs and wants" (International Technology Education Association [ITEA], 2007, p. 2) and being able to use, understand, and develop technology is vital to our society. Bybee (2010) suggested, "there are very few other things that influence our everyday existence more and about which citizens know less" (p. 30). Technology literacy is essential in enhancing the education of other subjects, which is vital for individuals to gain and maintain employment, as well as to participate in our ever-changing technological society.

Engineering Literacy

According to Moore et al. (2014), "Engineering requires that application of mathematics and science through the development of technologies, it can provide a way to integrate the STEM disciplines meaningfully" (p. 2). Engineering also provides real-world contexts that can used to teach mathematics and science through the engineering design process (Maiorca & Stohlmann, 2016). Engineering is an essential tool that can be used to integrate science, technology, and mathematics (Grubbs & Strimel, 2016; Moore et al., 2014). Therefore, it is increasingly important for teachers to be able to implement quality engineering design problems. The K-12 framework for quality K-12 engineering education focuses on students using the engineering design process to solve relevant problems, what an engineer is and does, and how they can impact the world (Moore et al., 2014). This framework includes 12 indicators for quality engineering problems: process of design (problem and background, plan and implement, and also test and evaluate), apply science, engineering and mathematics, engineering thinking, conceptions of engineers and engineering, engineering tools issues, solutions and impacts as well as ethics, teamwork, and communication related to engineering. Based on this framework, an engineering-literate person should know what engineers do, how engineering can be used to solve the challenges of today and make a better future for tomorrow. They also should be able to use the engineering design process to solve real-world problems that incorporate mathematics, science, and technology. The inclusion of engineering in the Next Generation Science Standards (NGSS) is "an unmistakable policy statement that science, technology, engineering and mathematics (STEM) integration is a desired outcome" (Roehrig, Moore, Wang & Park, 2012, p. 41).

Mathematical Literacy

In order to participate in society, individuals have always needed to have mathematical literacy, also more commonly referred to internationally as quantitative literacy (e.g., Steen, 2001). In 2003, the Program for International Student Assessment (PISA) stated that a mathematically literate person can use mathematics outside of the classroom in their personal and private lives (as cited in Kaiser & Willander, 2005). Steen, Turner and Burkhardt (2007) defined mathematical literacy as having the ability to use one's knowledge and understanding of mathematics in everyday life. Similarly, the Organisation for Economic Co-Operation and Development (OECD) defines mathematical literacy as the "capacity to formulate, employ, and interpret mathematics in a variety of contexts. It includes reasoning mathematically and using mathematics concepts, procedures, facts, and tools to describe, explain, and predict phenomena" (2016, p. 28). Mathematical literacy provides students with the knowledge to apply mathematics in other content areas and to their daily lives. The U.S. National Council of Teachers of Mathematics (2018) argues that in today's world, "mathematical literacy is needed more than ever to filter, understand, and act on the enormous amount of data and information that we encounter every day" (p. 1). In *Charting a Course for Success: America's Strategy for STEM Education* (Committee on STEM Education of the National Science and Technology Council, 2018), mathematics is rightfully positioned as foundational to success across the STEM fields and the importance of mathematical literacy as well as computational literacy and thinking are prioritized.

Summary

STEM disciplines have similar desired outcomes, and therefore, there should be some commonality across definitions of literacy for the subject areas. For example, disciplinary literacy approaches in science, technology, engineering, and mathematics all address problem solving in some way. For example, with technology literacy and engineering literacy, students design problems, create solutions, and evaluate design by considering effects on other technology or solving real-world problems (ITEA, 2007). Scientifically literate individuals formulate hypotheses, design and conduct experiments, make arguments with scientific evidence, consider alternate hypotheses, and interpret results (NRC, 2012). Mathematically literate students make conjectures, explore, justify conclusions with counter examples and evaluate the reasonableness of results (National Governors Association Center for Best Practices & Council of Chief State School Officers (CCSSO), 2010). To promote disciplinary literacy, individuals need to be given the opportunity and access to engage in authentic problems, and this requires the integration of different content areas (Cavalcanti, 2017). Because of this integration, STEM literacy should be considered not as siloed content literacies but as an integrated literacy (Zollman, 2012). These kinds of learning experiences promote not only literacy in the individual content areas but also integrated STEM literacy.

What Is STEM Literacy?

While there is no agreed-upon definition of STEM literacy, it is not because there have not been multiple attempts. This is likely due to the dynamic nature of the STEM field, and subsequently STEM literacy (Cavalcanti, 2017; Cavalcanti & Mohr-Schroeder, 2019; Zollman, 2012). However, the definition must remain dynamic and responsive to reflect the ever-changing society in which we live (Cavalcanti, 2017). Table 3.1 provides a non-exhaustive list of current, commonly used definitions of STEM literacy.

As one can see from the definitions in Table 3.1, there are a variety of interpretations. In a comparison study of the disciplinary literacies of STEM, Tang and Williams (2019) found similarities and differences, arguing that the following similarities can and should be used as a basis for a common STEM literacy definition:

- The creation, use, and conversion of codified multimodal representations.
- The mastery of common visual resources such as annotated diagrams and geometric drawings.
- The application of cognitive and metacognitive strategies involving problem identification, planning, and evaluation and self-monitoring.

The commonalities across the STEM disciplines and across the definitions provided in the literature reveal a unique tool set, especially as it relates to the ability to create and use knowledge in integrated STEM. The goal of any participant in an integrated STEM experience is to master the related outcomes as they learn how to create, communicate, and use knowledge within and across STEM. As Cavalcanti (2017) argues,

> Using the substantive literature on literacy within the STEM disciplines, it may behoove stakeholders to place more targeted attention to the themes of utility, social responsibility, response to change, communication, decision-making, and knowledge to define STEM literacy in a way that can be understood and applied across a variety of contexts.
>
> *(p. 65)*

In this light, we offer a dynamic, process, equitable and content-oriented definition of STEM literacy that holistically captures previously published work, is outcomes- and process-oriented, and honors the individual strengths each of the STEM disciplines brings, while focusing on integrated STEM as the cornerstone.

> *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.*

Regardless of how you define STEM literacy, a basic understanding of the STEM disciplines is necessary to be an informed decision-maker and member of a democratic and ever-changing society. Research has shown that greater exposure to a variety of STEM opportunities has a long-term effect on individuals (e.g., Wai, Lubinski, Benbow, & Steiger, 2010) and in formal and informal settings (e.g., Maiorca et al., 2020; Mohr-Schroeder et al., 2014; Roberts et al., 2018).

Table 3.1 Current, Commonly Used Definitions of STEM Literacy

Reference	*Definition*
National Governors Association (2007, p. 7)	STEM literacy refers to an individual's ability to apply his or her understanding of how the world works within and across four interrelated domains. STEM literacy is an interdisciplinary area of study that bridges the four areas of science, technology, engineering, and mathematics. STEM literacy does not simply mean achieving literacy in these four strands or silos.
Bybee (2010, p. 31)	STEM literacy includes the conceptual understandings and procedural skills and abilities for individuals to address STEM-related personal, social, and global issues. STEM literacy involves the integration of STEM disciplines and four interrelated and complementary components. STEM literacy refers to the following: • Acquiring scientific, technological, engineering, and mathematical knowledge and using that knowledge to identify issues, acquire new knowledge, and apply the knowledge to STEM-related issues. • Understanding the characteristic features of STEM disciplines as forms of human endeavors that include the processes of inquiry, design, and analysis. • Recognizing how STEM disciplines shape our material, intellectual, and cultural world. • Engaging in STEM-related issues and with the ideas of science, technology, engineering, and mathematics as concerned, affective, and constructive citizens.
Balka (2011, p. 7)	STEM literacy is the ability to identify, apply, and integrate concepts from science, technology, engineering, and mathematics to understand complex problems and to innovate to solve them. To understand and address the challenge of achieving STEM literacy for all students begins with understanding and defining its component parts and the relationships between them.
National Research Council (2011, p. 5)	STEM literacy is the knowledge and understanding of scientific and mathematical concepts and processes required for personal decision-making, participation in civic and cultural affairs, and economic productivity for all students.
Zollman (2012, p. 18)	STEM literacy is a dynamic process that spotlights the three strata in the STEM literacy process: educational objectives of the content areas; cognitive, affective, and psychomotor domains from learning theory; and economic, societal and personal needs of humanity.
Mohr-Schroeder, Cavalcanti, & Blyman (2015); Jackson & Mohr-Schroeder (2018, p. 43)	STEM literacy is the ability to apply concepts from science, technology, engineering, and mathematics to solve problems that cannot be solved using a single discipline.
Cavalcanti (2017, pp. 66–67)	STEM literacy may be defined as the conceptual understandings and procedural skills and abilities for individuals to address STEM-related personal, social, and global issues (Bybee, 2010, p. 31); the ability to engage in STEM specific discourse; a positive disposition toward STEM (e.g., Wilkins, 2000, 2010, 2015), including a willingness to engage and persist in STEM-related areas (e.g., Wilkins, 2000, 2010, 2015); an understanding of the utility of applying STEM concepts to solve real world problems; and, an appreciation of how the processes and practices of STEM areas change as technologies and demands of modern society change.

Critical Need for a STEM-Literate Society

STEM policy reports (such as Committee on STEM Education of the National Science & Technology Council, 2018; National Research Council, 2011; U.S. Department of Education, 2016) speak to the critical need and urgency of fostering STEM literacy in each and every student so that they can develop foundational knowledge in STEM regardless of whether or not they pursue a STEM career (for a critical review, see Bush, 2019). STEM literacy prepares students for adulthood and empowers them as informed members of a democratic society that can understand and make sound decisions on topics such as mortgages and investments; comparison shopping; interpreting medical documents; preserving the environment; analyzing a news report; and completing a home improvement project (Bush, 2019). National education professional organizations, such as the National Council of Teachers of Mathematics (2018), have highlighted areas of STEM literacy, such as mathematical and statistical literacy, for the same reason of helping our students become adults who are informed decision makers. Further, as described earlier in the science literacy section, the National Academies of Sciences, Engineering, and Medicine (2016) describes how individuals should be scientifically literate for four different reasons: economic, personal, democratic, and cultural. We contend that this idea geared at scientific literacy can be extended to STEM literacy and serve as a guide for schools, districts, and all STEM stakeholders as we consider in what ways do our students need to be STEM literate. As a field, we must ensure each and every student has opportunities to engage in a variety of experiences which will build their STEM literacy as they relate to economic, personal, democratic, and cultural considerations.

It is clear that students need more applicable, integrated, and authentic learning experiences. Our work centers on fostering STEM literacy specifically from that integrated approach, as we know that to solve complex problems in our communities and, more broadly, the world, knowledge from multiple disciplines must be applied. These integrated and authentic STEM experiences cannot simply be left to chance. Planning the best STEM experiences requires carefully considering the on-grade-level content and practices of focus and maintaining the integrity of the standards (Larson, 2017; NCSM/NCTM, 2018). Only through such intentional planning can we move away from disjointed integrated STEM "activities" which are often not authentic in nature (e.g., build a bridge, but for what purpose?) or which are fun and might even be engaging but do not align to grade-level learning goals (Bush & Cook, 2019).

Further, each and every student must have access to rich content-based authentic STEM experiences (Bush & Cook, 2019; Roberts et al., 2018). This includes in both formal and informal learning settings, with a push for STEM learning to become a foundational part of a student's school career, akin to reading, rather than a special, add-on, or enrichment program. Research and resources (e.g., Bush & Cook, 2019; Johnson, Peters-Burton, & Moore, 2016; Sahin & Mohr-Schroeder, 2019) are becoming more available to provide guidance to schools, districts, and states as they begin to develop long-term sustained STEM infrastructures to create systemic ways to ensure each and every student develops STEM literacy.

Conclusions

To be clear, we contend that STEM, and the development of STEM literacy, should become as natural a part of the school experience as literacy. STEM literacy *is* literacy. We argue that STEM literacy is not an option, as no matter a student's future career choice, each and every student should leave high school STEM literate so that they can be an informed consumer and decision maker in our ever-increasing information and data-rich society. As the recent report by the Committee on STEM Education of the National Science & Technology Council (2018) states, "A STEM-literate public will be better equipped to conduct thoughtful analyses and to sort through problems, propose innovative solutions, and handle rapid technological change, and will be better prepared to participate in civil society as jurors, voters, and consumers" (p. 5). The learning experiences that students receive to build their STEM literacy will impact the quality of their entire adult lives. In essence, STEM literacy is a vehicle through which to develop the 21st Century Learning Skills (as described by the National Education Association, 2012) while honing rich disciplinary content learning: critical thinking and problem solving, communication, collaboration, and creativity and innovative thinking. Even more important are opportunities to participate in problem solving that provides STEM literacy input and opportunities for output to scaffold and support mastery of the repertoire of practice. Experiences aimed at participants becoming STEM-literate "are shaped by and contribute to social practices, purposes, and contexts" (Moje, Collazo, Carrillo, & Marx, 2001, p. 472). For these reasons, it is critical that students are provided opportunity, access, and meaningful exposure to a STEM literacy community in which to participate, practice, and belong.

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