Learning for STEM Literacy: STEM Literacy for Learning

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We are in the STEM generation whose comprehensive purpose is to resolve (1) societal needs for new technological and scientific advances; (2) economic needs for national security; and (3) personal needs to become a fulfilled, productive, knowledgeable citizen. STEM specifically refers to science, technology, engineering, and mathematics, but now has a broader meaning to include environment, economics, and medicine. Currently, there is not an agreement of the particulars in education, or in standards, by professional organizations that define STEM literacy. Most definitions do cover societal and economic needs but overlook personal needs. There is a general consensus that everyone needs to be STEM literate. But there is a difference between literacy and being literate. STEM literacy should not be viewed as a content area but as a deictic means (composed of skills, abilities, factual knowledge, procedures, concepts, and metacognitive capacities) to gain further learning. This paper gives a brief background of literacy definitions in STEM and presents a description of STEM literacy based upon (1) cognitive, (2) affective, and (3) psychomotor learning theory domains. The paper stresses the need to evolve from learning for STEM literacy to using STEM literacy for learning to satisfy our societal, economic, and personal needs.

Introduction

Since 1944, the United States has commissioned reports with similar charges—identify solutions to the dearth of scientific talent. The first report, Science, the Endless Frontier (Bush, 1945), was a response to the competitive challenges in science from Germany and Japan. Through the years, hundreds of related reports and programs have followed. The current White House program, Educate to Innovate (2010), aims to help student excel in science, technology, engineering, and mathematics (STEM). All these reports and programs have analogous concerns: the future need for more scientists, technicians, engineers, and mathematicians (the supply pipeline); the necessity for more innovative workers (a knowledgeable population) trained in science, technology, engineering, and mathematics; and recommendations for what schools should do to solve the shortage. Their overarching purpose is to resolve (1) societal needs for new technological and scientific advances; (2) economic needs for national security; and (3) personal needs to become a fulfilled, productive, knowledgeable citizen.

We now are in the STEM generation. STEM specifically refers to science, technology, engineering, and mathematics, a term coined in 2001 by Judith Ramaley as the assistant director of the Education and Human Resources Directorate at the National Science Foundation. STEM now has a broader meaning, and includes agriculture, environment, economics, education, and medicine (Zollman, 2011). (Some say it should be STEAM, to include the arts and creativity-related components [Tarnoff, 2010]).

There is a general consensus that everyone needs to be STEM literate, but there is a difference between literacy and being literate. STEM literacy should not be viewed as a content area but as a shifting, deictic means (composed of skills, abilities, factual knowledge, procedures, concepts, and metacognitive capacities) to gain further learning. Currently, there is not an agreement of the particulars in education, or in standards, by professional organizations that define STEM literacy. Most definitions do cover the societal and the economic needs but overlook the personal needs. This paper provides a background of literacy definitions in the four STEM strands, and presents a description of STEM literacy based upon three domains of learning: (1) cognitive, (2) affective, and (3) psychomotor from educational learning theory. This paper stresses the need to evolve from learning for STEM literacy to using STEM literacy for learning to satisfy our societal, economic, and personal needs.

Literacy and STEM Background

Read the following sentences carefully and answer the ensuing two questions.

A mayber was railing his temp. Saintly a durf accotted some padis in the mayber’s temp.

Question 1: What did the durf accot in the mayber’s temp?

Question 2: Why did the durf accot padis in the mayber’s temp?

Question 1 can be answered correctly, “The durf accotted padis in the mayber’s temp.” However, Question 2 cannot be answered. It is an analysis question that requires...
understanding to answer why. The two sentences with the mayber and the durf are made-up nonsense, so there can be no understanding. For Question 1, we can be literate but for Question 2, we need more—we need literacy.

Traditionally, being literate was viewed as the ability to read and write, but now literacy encompasses more than these two capabilities. Shanahan (1992) includes recognition, fluency, comprehension, and composition. The National Council of Teachers of English states that twenty-first-century readers and writers need to:

1. develop proficiency with the tools of technology;
2. build relationships with others to pose and solve problems collaboratively and cross-culturally;
3. design and share information for global communities to meet a variety of purposes;
4. manage, analyze, and synthesize multiple streams of simultaneous information;
5. create, critique, analyze, and evaluate multimedia texts; and
6. attend to the ethical responsibilities required by these complex environments (NCTE, 2008).

UNESCO (2008) goes further: Literacy involves a continuum of learning in enabling individuals to achieve their goals, to develop their knowledge and potential, and to participate fully in their community and wider society. This definition is coupled to UNESCO’s four pillars of learning: (1) learning to know, (2) learning to do, (3) learning to live together, and (4) learning to be. Literacy now is interwoven with traditional language processing, multimodal digital technologies, and social practices of communications (Lankshear & Knobel, 2006). Literacy is deictic; it is constantly changing as new technology develops (Leu et al., 2007).

Similarly, STEM literacy now is more than the four separately defined literacy strands (“silos”) of science, technology, engineering, and mathematics, as described in Table 1. According to the National Science Education Standards (National Research Council, 1996) and the Organization for Economic Cooperation and Development (2003), scientific literacy is the knowledge and understanding of scientific concepts and processes required for personal decision making, participation in civic and cultural affairs, and economic productivity. It includes the ability to use scientific knowledge (in physics, chemistry, biological sciences, and earth/space sciences) and processes to understand, and additionally, to participate in decisions that affect science in life and health, earth and environment, and technology.

The National Assessment of Education Progress is developing assessments for technology and engineering proficiency. They define technological literacy as the capacity to use, understand, and evaluate technology, as well as to understand technological principles and strategies needed to develop solutions and achieve goals (National Assessment Governing Board, 2010). The International Society for Technology in Education further includes the ability to demonstrate creativity and innovation, communicate and collaborate, conduct research and use information, think critically, solve problems, make decisions, and use technology effectively and productively (2000). A third organization, the International Technology Education Association, includes the ability to understand, in increasing sophistication over time, how technology is created, and how it shapes society, and additionally, is shaped by society (2007).

The Organization for Economic Cooperation and Development (2003) describes engineering literacy as the understanding of how technologies are developed via the engineering design process. This incorporates the ability to systematically and creatively apply scientific and mathematical principles to practical ends, such as the design, manufacture, and operation of efficient and economical structures, machines, processes, and systems. The Accreditation Board for Engineering and Technology includes knowledge of the mathematical and natural sciences gained by study, experience, and practices that are applied to develop ways to utilize economically the materials and forces of nature for the benefit of mankind (2010).

Mathematical literacy is defined in the Program for International Student Assessment (PISA) as the capacity to identify, understand, and engage in mathematics. PISA includes the ability to make well-founded judgments about the role that mathematics plays in an individual’s private life, occupational life, and social life, as well as life as a constructive, concerned, and reflective citizen (Organization for Economic Cooperation and Development, 2006). The National Council of Teachers of Mathematics defines mathematical literacy (also called numeracy) as the ability to read, listen, think creatively, and communicate about problem situations, mathematical representations, and solutions to develop and deepen understanding of mathematics (2000).

From Table 1, the professional organization literacy definitions do overlap. All these separate literacy definitions speak on the importance of knowledge and understanding. Most definitions mention the importance of applying and evaluating. Two of the definitions even discuss creating/applying knowledge, skills, and abilities to goals in their respective content areas. These
<table>
<thead>
<tr>
<th>Literacy</th>
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<tr>
<td>Scientific Literacy</td>
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<td>Technological Literacy</td>
<td>National Assessment Governing Board (2010)</td>
<td>Capacity to use, understand, and evaluate technology, as well as to understand technological principles and strategies needed to develop solutions and achieve goals</td>
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<td>Engineering Literacy</td>
<td>Organization for Economic Cooperation and Development (2003)</td>
<td>Ability to systematically and creatively apply scientific and mathematical principles to practical ends such as the design, manufacture, and operation of efficient and economical structures, machines, processes, and systems</td>
</tr>
<tr>
<td></td>
<td>Accreditation Board for Engineering and Technology (2010)</td>
<td>Knowledge of the mathematical and natural sciences gained by study, experience, and practices that is applied to develop ways to utilize economically the materials and forces of nature for the benefit of mankind</td>
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<tr>
<td>Mathematical Literacy (Numeracy)</td>
<td>Program for International Student Assessment (2006)</td>
<td>Capacity to identify, understand, and engage in mathematics, and to make well-founded judgments about the role that mathematics plays in an individual’s current and future private life, occupational life, social life with peers and relatives, and life as a constructive, concerned, and reflective citizen</td>
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professional organization literacy definitions focus on (1) society and (2) economic needs.

STEM literacy does not simply mean achieving literacy in these four strands (Toulmin & Meghan, 2007). It also means more than mapping the numerous overlapping interdisciplinary skills, concepts, and processes. STEM literacy is the synergy of these literacy strands—where the total is much more the sum of the individual parts. Extending these ideas, only the PISA (2006) slightly mentions the (3) individual’s needs.

Nobel laureate physicist Leon Lederman approaches this aspect when he describes STEM literacy as the ability to adapt to and accept changes driven by new technology work, to anticipate the multilevel impacts of their actions, to communicate complex ideas effectively to a variety of audiences, and perhaps most importantly, to find measured, yet creative, solutions to problems that are today unimaginable (1998).

This is learning for the purpose of STEM literacy, not STEM literacy for the purpose of learning. STEM literacy needs to go beyond content and beyond processes, although these are vital elements. Learning for STEM literacy may accomplish our societal needs and our economic needs, but what about personal needs to become a fulfilled, productive, knowledgeable citizen?

The Domains of STEM Literacy in Education

There are three major problems with the current STEM literacy definitions. First, constructing a definition of STEM literacy by adding the four separately defined literacy strands of science, technology, engineering, and mathematics together dilutes the essence of each. Second, such a compilation listing neglects the synergy of the four strands. Third, it does not realize the personal needs of the individual. We want to have STEM literacy to further learning for economic, societal, and personal needs—going beyond “learning to know and learning to do” to “learning to live together and learning to be.”

Perhaps a better approach is to reflect on widely used educational learning theory, such as Bloom’s Taxonomy of Educational Objectives (1956). In 1948, Benjamin Bloom chaired a committee of educational psychologists to develop a system of categories of learning behavior for the design and assessment of educational learning. Criticism of Bloom’s taxonomy comes from some who misinterpret it as hierarchical, meaning one needs always to begin at the lower levels of the cognitive domain and go step-by-step through all the levels. However, there is a renewed interest in Bloom’s taxonomy—Bloom’s Digital Taxonomy, sparked by informational and technological advances as an extension of student access to knowledge (Fisher, 2009), as illustrated in Figure 1. For example, remembering factual knowledge now might require doing a Boolean algebra search on Google.

Bloom’s taxonomy model categorizes learning into three domains: cognitive domain (knowledge and processes), affective domain (attitudes and beliefs), and psychomotor domain (manual and physical skills) (Anderson & Krathwohl, 2001; Bloom & Krathwohl, 1956; Krathwohl, Bloom, & Masia, 1964). For a complete description of STEM literacy, all three learning domains (cognitive, affective, and psychomotor) are necessary.

Thus, a deictic description for developing STEM literacy needs to spotlight three strata: (1) literacies of science, technology, engineering, mathematics, and other associated areas; (2) personal, societal, and economic needs; and (3) cognitive, affective, and psychomotor learning domains. Figure 2 shows a graphical representation of these three strata in the STEM literacy process. For example, with respect to the personal needs of a student, the student must operate technology efficiently (e.g., muscle memory for typing); personally obtain competence and value the sciences; and be able to apply factual, procedural, and conceptual knowledge to solve problems and attain personal goals.

How to Develop, Apply, and Support STEM Literacy in the Classroom

To evolve from learning for STEM literacy to a process of STEM literacy for learning, four main aspects need to be considered by the curriculum and by the teacher. First, the STEM areas cannot be viewed as independent silos of content. For example, there cannot be a separate engineering curriculum and a technology curriculum. STEM should be viewed as a metadiscipline, the creation of a discipline based on the integration of other disciplines into a new whole (Kaufman, Moss, & Osborn, 2003; Morrison, 2006). Second, content and pedagogy also must blend; as mentioned in the National Science Education Standards (National Research Council, 1996), “There should be less emphasis on activities that demonstrate and verify science content” and more emphasis on those “that investigate and analyze science questions” (p. 113). This means a reduced concern for covering content and an increased emphasis in helping a student learn. Third, student attitudes, beliefs, self-esteem, self-confidence, and motivation must be considered. A student’s self-identity must be nurtured to value STEM. Fourth, a student needs to operate STEM technologies autonomically, efficiently.
Figure 1. Bloom’s Digital Taxonomy.

Figure 2. Spotlighting the Three Strata in the STEM Literacy Process.
Cognitive Domain and Reflection

With respect to the first learning domain of STEM literacy, cognitive domain, why does one student learn (gains literacy) while another student in the same class does not (Zollman, Smith, & Reisdorf, 2011)? Cognitive understanding occurs when the student decodes, conceptualizes, and applies the content—then reflects. Piaget (Beth & Piaget, 1966) states that students construct knowledge through the process of reflective abstraction. Piaget (Beth & Piaget, 1966) describes four constructs of reflective abstraction: interiorization, coordination, encapsulation, and generalization. Dubinsky (1991) refines the concept of reversal into a fifth construct.

Interiorization is a translation of successive actions into a construction of an internal process. Coordination is the process of synchronizing two or more processes to obtain a new process. Encapsulation is the conversion of a dynamic process into a static process—a thematic object of thought. Generalization occurs when a student applies an existing schema to a wider collection of concept. Reversal occurs when a student constructs a new structure by undoing the processes of a known structure (Beth & Piaget, 1966; Dubinsky, 1991).

These five reflective abstraction constructs are the basis of successful STEM education activities and projects. Many of these projects propose problem-based learning (PBL) as a method to synthesize mathematics, engineering, technology, and the sciences for critical thinking, creativity, innovation, and real-world problem solving. In learning material in the context it is used, both retention of material and transfer of learning are enhanced. Research findings on PBL show students also learn how to work collaboratively and communicate clearly (Duch, Groh, & Allen, 2001). Initiated by the teacher or by the curriculum, PBL requires interiorization, coordination, encapsulation, generalization, and reversal constructs.

Affective Domain and Identity Development

In the second domain for STEM literacy, all affects—motivation, self-esteem, self-confidence, beliefs and attitudes—are associated with personal identity strivings. According to Nakkula (2008), identity is the embodiment of self-understanding, and identity formation is the fundamental development task of psychological maturity during the adolescent years (Erikson, 1968). Students initiate identity work as they begin to think about their competencies and attributes, set short- and long-term goals, and evaluate personal beliefs. Classroom teacher actions create the appropriate classroom conditions for this identity work to flourish (Zollman et al., 2011).

In the affective domain for STEM literacy, four broad classes of teacher actions comprise classroom identity work: (1) fostering self-determination, (2) cultivating self-regulation, (3) capitalizing on collaborative social goals, and (4) establishing an engaging classroom environment (Zollman et al., 2011). Teachers create classroom conditions that nurture student needs for self-determination by providing opportunities for students to make choices, demonstrate their competency, and participate in supportive peer relationships. They teach, support, and encourage student self-regulation behaviors, thereby helping students evaluate their progress toward desired goals. Such teachers also encourage student exploration of positive possible selves to connect learning to considerations of their future lives. Rather than discouraging social interaction among students, teachers who engage in identity work expressly encourage and support student peer relationships and achievement of collaborative social goals. Employing pedagogical practices such as cooperative, authentic learning enables students to work and learn together. Finally, the engaging classroom environment emphasizes student effort, improvement, and mastery with an eye toward helping all learners not only feel confident but be competent in STEM (Zollman et al., 2011).

Psychomotor Domain and Physical Skill

The psychomotor domain, the third learning domain of STEM literacy, is demonstrated by physical skills such as movement, coordination, manipulation, dexterity, grace, strength, and speed, and actions that demonstrate fine motor skills as in the accurate use of precision instruments or tools. In the psychomotor domain, there are three stages (Dave, 1970; Romiszowski, 1999): thinking (cognitive), linking (associative), and autonomic (physical dexterity). Awkward, slow movements mark the thinking stage where the learner is consciously trying to control actions. Performance is generally poor, and the student makes many errors in sluggish, choppy movements. Frustration level is high, but diligent practice helps the student improve.

In the linking stage, the student begins to associate one movement with another known movement (Dave, 1970; Romiszowski, 1999). The student still must think about every movement. However, the movements begin to look smoother, and the student feels less awkward. Autonomic state is reached when learning almost is complete, although an individual can continue to refine the skill through practice (Dave, 1970; Romiszowski, 1999). The student no longer needs to depend on the teacher for feedback about performance. Motions and movements
become spontaneous. The learner no longer has to think about the movement; mind and body are one.

Traditionally, there has been less emphasis on the psychomotor domain than the cognitive and affective domains in STEM literacy. Technological advances quickly change the psychomotor domain skills needed. For example, instructional technology still includes touch-typing keyboard skills, but these lessons are now in the elementary, not the secondary school curriculum. With voice-synchronization technology, typing skills may become unnecessary in the near future.

Correspondingly, there are no classes to teach students how to text quickly on a smart phone, but many students are quite dexterous and efficient. To become proficient, students begin with copying the actions of their friends, and then repeatedly practice the skill, becoming more adept and autonomic in the process. Here, a student self-developed model for autonomic muscle memory is most prevalent.

### Getting From Learning for STEM Literacy to STEM Literacy for Learning

A common definition of STEM literacy is: “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” (Balka, 2011, p. 7). This definition is limited to societal and economic needs, but is lacking in personal needs.

This paper’s purpose is to evolve from “learning to know and learning to do” to “learning to live together and learning to be” in STEM literacy. There are good examples of developmentally appropriate curricula (e.g., Engineering—Go For It, 2010; PBS Design Squad Nation, 2011; Project Lead the Way, 2010) in STEM education that identify, apply, and integrate the learning to know and learning to do. However, educators carefully need to plan these activities and lessons to replace existing curricula, and not to add on to the already overcrowded school day. Effective lesson implementation is a key factor in identifying which topics in the current curriculum may be replaced. Added student benefits of these projects are the communication and team collaboration skills students learn while working on problem-based lessons—for learning to live together. Quality teachers go beyond lesson objectives to stress student identity development for self-regulation and self-determination behaviors for students learning to be.

In education, we need to view STEM literacy as a dynamic process, spotlighting 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. Such a vision allows us to evolve from focusing on learning for STEM literacy to using STEM literacy for continued learning.

### References


Author’s Notes

Keywords: STEM literacy; literacy definition; Bloom’s taxonomy; learning domains; cognitive; affective; psychomotor.