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Conceptualizations and Limitations of STEM Literacy across Learning Theories

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The concept of literacy is relevant in many areas of life, both inside and out of the classroom. With science, technology, engineering, and math (STEM) being fast-growing fields, STEM literacy in particular holds an important place in today's education system and beyond. While there is not a single definition for STEM literacy, it is impacted by possible assumptions educators make about students and the learning process. These assumptions are derived from many sources, including personal beliefs, past experiences, and learning theories that individuals utilize. This paper discusses the conceptualizations of STEM literacy and related limitations within three different learning theories: information processing, constructivism, and sociocultural theory. A theoretical framework is then discussed that addresses these limitations and incorporates a sociopolitical lens on scientific literacy, for the sake of helping educators identify and adjust their own perceptions for the sake of better supporting students.

KEYWORDS STEM literacy, information processing, constructivism, sociocultural lens, sociopolitical lens

PERSPECTIVE

The importance of science, technology, engineering, and math (STEM) education is well-documented and discussed throughout education and STEM fields alike (1). Part of this push for increased STEM education includes the idea of what it means to have STEM literacy. Historically, STEM literacy, which we mean to include scientific, technology, engineering, and mathematical literacy, has been an elusive term in STEM education (2). In many settings, it has come to be an umbrella concept to refer to efforts of STEM teaching in schools (2). For this reason, there are many ways in which STEM literacy can be conceptualized according to theoretical assumptions about teaching and learning. Because these conceptualizations are inherently intertwined with societal power structures, notions surrounding STEM literacy can also be used as a way to empower students in STEM classrooms, or as a way of oppressing students from marginalized groups (3, 4).

To our knowledge, there is not existing literature on how conceptions of STEM literacy develop, even implicitly, from potentially problematic views of learners. This paper addresses three learning theories to unpack underlying assumptions of several predominant conceptions of STEM literacy. In particular, we focus on the learning theories of information processing (IP), constructivism, and sociocultural theory for two reasons. First, these are three of the most often used theoretical frameworks in the field of STEM education. Second, we found that these three theories provide distinct conceptions of STEM literacy. We draw specifically on conceptions of literacy presented by Laugksch (2), Norris and Phillips (5), and Solomon (6) and connect these conceptions to the three learning theories. We then offer some limitations associated with holding such assumptions about learners and learning according to the learning theory that underlies the conception. Finally, we connect these limitations (which typically take the form of disenfranchising students) to critical perspectives which address sociopolitical considerations. We do this for the sake of allowing educators to consider their own perceptions of STEM learning and literacy and to make adjustments as needed that might better impact their students in the future.

Theoretical background

Learning theories provide various conceptualizations of learners, their interaction with information, and the nature of learning itself. These varied perspectives on learning impact each theory's conceptualization of STEM literacy. Since certain views of literacy have long been used to perpetuate forms of systematic oppression (3, 7), how learning theories explain literacy can have wide-scale implications. We first outline three learning theories, information processing, constructivism, and sociocultural theory, to provide

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background information about how STEM literacy can be conceptualized from these various frameworks.

(i) Information processing. IP theory is governed by several main beliefs: (i) the mind is an information processor (i.e., computer) that manipulates abstract information (8); (ii) knowledge is the production of abstract information into rules, or if-then statements (9); and (iii) learning is the process by which an individual becomes more proficient in using these rules. Someone who has achieved a certain level of proficiency by demonstrating the ability to make meaningful patterns of information during-problem solving, and using flexible approaches to novel situations, is considered an "expert." The label of "novice" is given to those who have not yet reached such a level of mastery (10). Teaching and learning from an IP perspective emphasize one's ability to gain proficiency on problem-solving tasks and to efficiently process content knowledge, growing from a novice to an expert.

(ii) Constructivism. The learning theory of constructivism centers the active role learners play in the construction of their knowledge during the learning process (11). Prominent assumptions under constructivism include the following: (i) individuals have existing conceptual structures, called schemas, based on their own prior experiences (12); (ii) learners construct knowledge by either assimilating new information into existing schemas or altering schemas to accommodate that information (12, 13); and (iii) individuals see the world relative to their own experiences rather than as objective reality (14). Learners interpret information in a manner that aligns with their current understandings and evolves as needed based on new information. The constructed schemas are influenced by the learner's life experiences and, therefore, impact their view of the world around them.

(iii) Sociocultural theory. The sociocultural learning theory perspective highlights several key ideas: (i) cognition originates in social experiences; (ii) mediational tools play a part in the development of cognition; and (iii) language and thought are deeply intertwined (15). The social origin of cognition refers to the idea that individuals learn through participation in social practices, experiencing them first at the social level and subsequently adopting them for use at the individual level (16, 17). This process of internalization often coincides with the use of cultural tools used to mediate thinking, meaning they are central to how one engages with or even defines an activity (15, 16). Language is the most consequential cultural tool from a sociocultural perspective. As individuals adopt language, their external speech becomes internal thought, making the connection between language and thought deterministic (18). Under this perspective, a learner that is able to use cultural tools to mediate thought, internalizing cultural practices as they do so, is one who is considered to be successful.

Conceptualizations of STEM literacy

(i) Information processing and STEM literacy. We view IP as aligning well with one of Laugksch's (2) conceptions of STEM literacy, which they call "literate as competent." This definition of literacy is characterized by the extent to which an individual is "competent," which is marked by their ability to carry out certain tasks, as well as their ability to communicate to a third party about scientific matters, suggesting some involvement in society. Additionally, literate as competent interpretations view science content knowledge as existing outside the mind, to be mastered by the individual. We see this conception of literacy as implicitly holding IP perspectives in several ways. First, the focus on competence is analogous to the ways in which the National Research Council (10) describes expertise. Those who are literate as competent can also be viewed as experts, where one's literacy is measured by one's ability to flexibly approach new problems and navigate various problem contexts. Second, IP theory views science knowledge as existing in the external world and is then operated on internally via formal rules, similar to conceptions of literate as competent. We view an IP perspective of scientific literacy as involving one's ability to perform certain tasks, as having some involvement with the external world, and in viewing literacy as being in reference to an existing body of knowledge that is to be mentally processed by the mind.

(ii) Constructivism and STEM literacy. The constructivist perspective on learning can be used to frame a conceptualization of STEM literacy described by Norris and Phillips (5), who used similar underlying principles about knowledge and the learner. They explained that knowledge is not linearly built but it is dependent on all the discourse (i.e., what is being communicated both verbally and nonverbally in a classroom) surrounding that knowledge, with written text being a critical component. This parallels assumptions in constructivism, as nonlinear knowledge building is reflected in mental schemas; these schemas are connected pieces of information with no prescribed structure. Additionally, STEM literacy conceptualized in this manner emphasizes the way that an individual is interpreting the content and how the text is allowing interpretation from the reader (5), which parallels the constructivist view of a subjective reality based on an individual's experiences. A final aspect of literacy that Norris and Phillips (5) characterized is that neither the text nor the reader is supreme. Constructivism places value on the individual learner's active role in knowledge building and, thus, does not view the text as superior to the learner.

(iii) Sociocultural theory and STEM literacy. Solomon (6) provided an example of adopting a sociocultural lens to STEM literacy. She framed mathematics as a social and cultural activity and asserted that in order to attain mathematical literacy, learners need to develop identities of participation. That is, participation in mathematical social practices is foundational in shaping identities that lead to mathematical literacy. In addition to activity, the nature of participation and a person's positioning as a "math or science person" is interpreted through the values, assumptions, and rules of the classroom community. These values, assumptions, and rules are mediational tools that members of the class use to interpret their own and others' positioning in the classroom. Finally, Solomon echoed the idea

that much of learning happens linguistically by describing mathematics learning as the individualizing of mathematics discourse and the process of becoming able to communicate mathematically with oneself and others. Discourse about STEM is what Solomon viewed as leading to an identity of participation, and thus STEM literacy.

DISCUSSION

While these three learning theories offer insightful perspectives on how to conceptualize what it means to be STEM literate, as summarized in Table 1, there are also limitations underlying these theoretical assumptions. We now discuss some of the limitations of each conceptualization with the hope of helping educators identify their own beliefs about learning and learners and how those beliefs can possibly be expanded to incorporate sociopolitical factors impacting students.

Limitations of learning perspectives of STEM literacy

From an IP perspective, the emphasis on experts narrows the criteria by which someone could be considered scientifically literate. This creates limitations to the types of competence that could otherwise be ascribed to various STEM learners and their state of literacy, based on who is ascribed as experts within the field. For instance, viewing literacy as competent or as an adaptive expert might be exclusionary to students who consume mathematics and science in nontraditional ways. Limitations of constructivism include the lack of emphasis placed on the learning environment and other social factors that can impact student understanding. While this conceptualization centers the role of the individual in their process of gaining literacy, it does not consider the roles of outside participants in the community. This excludes potential influences, such as the classroom social dynamics and the students' lives outside of school. A limitation of a sociocultural perspective includes the assumption that all students in the classroom will have access to practices that lead to successful learning; this assumption dismisses the varied access students face at regional and classroom levels, such as socioeconomic factors and positionality in the classroom.

Impact of limitations

As we have articulated how literacy might be defined under various learning theory lenses, it is important to also discuss how conceptualizations of STEM literacy have been used throughout history to perpetuate forms of oppression. Within the American education system, primarily in K–12 education, we see the ubiquitous nature of standardized testing, commonly taking the form of literacy tests. Such measures of literacy, based on a false belief in meritocracy (e.g., equating one's value in society with socioeconomic status), have been shown to further perpetuate equity gaps within education and, thus, can lead to many minoritized students being tracked away from STEM fields and not given the opportunities they deserve to succeed (4, 7, 19, 20).

With the focus on mastery, we see connections between information processing's conceptualization of literacy and the oppression that can occur from standardized testing. While there is a focus on mastery, there is a lack of focus on helping students bridge the gap from novice to expert, overlooking many students who are already on the margins. When considering the limitations of constructivism, it is less clear in this framework where authority lies in deciding on what the most important aspects of a subject are. For example, educators could demonstrate multiple solution strategies during class, only for students to be penalized on standardized exams for not choosing a perspective that aligns with the "authority" figure who decided what strategies were valid on a given test.

Another subtle yet impactful form of oppression with connections to notions of literacy are deficit perspectives. Deficit perspectives are when one emphasizes the way in which a student has not assimilated to a given set of science norms (i.e., the standard science culture), rather than focusing on the schemas and skills that a student does have regarding a particular subject. These deficit perspectives can impact learners within the classroom by teachers who subscribe to incorrect assumptions about various learners, inflicting microaggressions or positioning students in less-than-productive ways (21–23). We see connections to deficit perspectives among the limitations of IP and socioculturalism. Within information processing, the focus of what it means to be an expert in the field creates a hierarchy of knowledge that only values certain types of mastery or skills and not others. Within socioculturalism, all learners are expected to enculturate into a community of practice in similar ways, with no alternatives provided to learners who might navigate the world in a different way or ultimately allowing room for deficit perspectives in regard to those learners.

With these considerations of oppression with regard to literacy, we introduce a critical approach toward the way literacy is defined. We next discuss how adding this critical lens to literacy can help to address some of these oppressive tendencies that prior conceptions of literacy have allowed and suggest a more holistic definition to literacy that encompasses this critical element.

Critical perspectives

As we have discussed some of the limitations of these three learning theories above, we now point out that by asking about the power dynamics at play in a learning environment, many of these limitations can be addressed. Considering these power dynamics can also be described as taking a sociopolitical perspective (24). By considering who is seen as "valid" within the framework of IP, we acknowledge power structures that traditionally give certain types of mastery primacy over others, which perpetuate various

TABLE 1
Learning theories and associated STEM literacy conceptualizations

Learning theory	Assumptions of theory	Conceptualization of STEM literacy
Information processing	• Mind functions as a computer • Knowledge is creating if-then rules • Learning is becoming more proficient at executing if-then rules	• Can carry out certain tasks and communicate science content • Knowledge exists outside the mind
Constructivism	• Knowledge is organized in schemas • New information is assimilated into schemas, otherwise schemas are altered to accommodate information • Reality is subjective	• Knowledge is dependent on all discourse surrounding the topic • Written text is crucial but not superior nor inferior to reader
Sociocultural Theory	• Social origins of cognition • Tools mediate cognition • Language and thought are intertwined	• Learners develop identities of participation • To be a "math or science person" is based on values, assumptions, and rules of classroom community • Mathematics learning is becoming able to communicate mathematics with oneself and others

forms of oppression. By considering and attending to who has authority within a constructivist lens, we realize that overlooking this element also means that certain students can be overlooked if their ideas do not align with the authority figure in a classroom. Considering what tools are required for students to access various practices within STEM education allows us to more fully recognize how students may not have the same opportunities for enculturation. Such awareness then allows us to begin to attend to the differentiated needs of various learners.

Jackson et al. (25) proposed a framework for scientific literacy that attends to a sociopolitical perspective, where the outcome of scientific literacy aims at producing the next generation of change agents to help address inequities within society. While we do not suggest this framework as a perfect way to address or define literacy, we do highlight its ability to address some of the previously discussed shortcomings in defining STEM literacy.

The equity-oriented STEM literacy framework (25) proposes specific dimensions that may allow for a more holistic definition compared to those we have previously discussed in this paper. Some of these dimensions include identity, empowerment, and empathy. To expand on some of these ideas, attending to identity means being aware of the diversity of experiential knowledge in one's classroom, which is one way to address the assumption made in a sociocultural perspective that everyone has access to the practice of enculturation. Additionally, attending to the empowerment of an individual helps to counter the beliefs of IP that only certain ways of knowing are considered mastery, and also allows space to focus on empowering all students rather than only those who fit traditional molds of STEM literacy. Finally, we see empathy as an important tool when considering authority figures to add to a constructivist perspective. Because empathy attends to more than just traditional STEM content, authority figures and students may connect the ideas they consider important to their everyday lives into STEM learning, thus valuing their agency and personal authority.

An example of incorporating elements of identity, empowerment, and empathy in the classroom can be seen in works by Schenkel and Calabrese Barton (26). They explored middle school students' projects designed to improve the classroom community. These projects included things such as an accomplishments board for student successes and a light-up limbo stick to introduce more "fun" activities into the day. The analysis of these project constructions examined how the students interacted with different power hierarchies throughout the process and roles their identity may play in those negotiations. They investigated how some hierarchies, such as male classmates being viewed as superior to female peers, were followed by the group members, while others, such as classroom-level injustices of racial discrimination, were challenged and critiqued by the project designs and the empowered students. For further examples of the impacts such a framing of STEM literacy can have on students in the classroom, we encourage readers to review the cited references in this article.

CONCLUSION

In this paper, we have discussed the learning theories of IP, constructivism, and socioculturalism, and how STEM literacy can be conceptualized by each of them. While each of

these theories provides unique and valuable insight to what literacy can mean, each on its own also misses important aspects of literacy that can overlook the abilities of STEM learners and what they can accomplish. While we do not propose a perfect theory that addresses these concerns, we do suggest that a framework, such as the one proposed by Jackson et al. (25), which emphasizes sociopolitical elements of STEM literacy, is a way for educators to better ensure that their beliefs about STEM literacy are encompassing the full student. Our hope is that this article gives educators cause for reflection to consider how they frame learning and to see if their perspective considers the sociopolitical factors that are impacting their students. By incorporating elements of identity, empowerment, and empathy into the STEM classroom, educators may aid in mitigating barriers of learning for students (24–26). Most importantly, we see such an expansion of the definition of STEM literacy broadening the possibilities of innovation within STEM fields and brightening the futures of the students involved who will help carve those paths.

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