

(Re)Defining Scientific Wealth: Exploring Economic and Sociocultural Currencies in STEM Education

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Chapter Highlights

The following points outline key conceptual perspectives that frame STEM learning through sociocultural and economic lenses, emphasising knowledge exchange, value systems, and the development of students' scientific wealth.

- **Exchange of Knowledge** – Learners engage in the continual exchange of knowledge and meaning within formal and informal STEM learning spaces.
- **Scientific Currencies and Scientific Wealth** – In STEM classrooms, learners participate in the exchange of currencies that include language, skills, identity, and culture. I analogize such economic and sociocultural traditions as currencies that circulate within STEM education contexts that ultimately cultivate students' scientific wealth. This metaphor offers an opportunity to reframe traditional notions of the value attached to STEM education
- **Economic Motivations for STEM Education** – Historical trends indicate that economic motivations – such as national security and global competitiveness – undergird growth of STEM education in the U.S.
- **Tenets of Sociocultural Theories** – The tenets of sociocultural perspectives reveal valuable modes of currency – such as language, identity, and shared experience – that are under exchange within STEM education spaces that are unaccounted for by economic perspectives alone.

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Introduction

I was in ninth grade when I first felt like a scientist. I had recently joined my junior high school's Science Olympiad team at the encouragement of my favorite teacher – Mrs. K. Founded in 1984, Science Olympiad is a nonprofit organization positioned as the “premier team STEM competition in the nation” (Science Olympiad, n.d.). Similar to a STEM-themed track meet, students competed in science events through regional, state, and national competitions. Not only did I enjoy science, but all of my great friends were already on my school team. It seemed a natural fit for me to join. At the time, I was unaware of how much this decision would shape my future.

I spent four years as a student participant in the Science Olympiad. These experiences involved working with my peers and coaches to build efficient balsa wood towers that we would later test against other schools. As a senior, my partner McKenzie and I designed a science-inspired Rube Goldberg-esque contraption for a rather maniacal event named Mission Possible (if you know, you know). In another event called Write It Do It, my partner Kelly and I took technical writing to a new level. The competition saw me write instructions for how to construct an object using craft supplies. My instructions were then passed to Kelly, who was given the raw materials to construct the object from scratch using only my written instructions. This event required us to be perfectly in sync yet apart; perfect communicators, but without speaking. No big deal – but we won that event at the New York state tournament twice. Overall, competitions always involved pre-dawn competition day arrivals at tournament sites. When I was successful at an event, I felt a sense of personal satisfaction that remains unrivaled in my psyche. During my college years, I returned annually to supervise an event and meet up with former competition teammates and coaches. We pick up conversations left unfinished a year prior like no time has passed at all – delighted by seeing each other reach new milestones in science and in our personal lives.

In the aforementioned anecdotes, I engaged in currencies of exchange with my peers that accumulated into what I deem to be scientific wealth. These currencies included my scientific language and communication skills, sense of teamwork and collaboration, and my science identity (a trait I had always possessed but never fully actualized until I joined Science Olympiad). Such currencies could not be captured by any traditional measure of science achievement such as standardized tests or other benchmarks. Nonetheless, I shaped and was shaped by these currencies during my time in the organization. These currencies amassed into scientific wealth, which

I define as a science learner's affluence accrued from engaging in authentic, high-impact scientific practices.

In this chapter, I ask, how can sociocultural perspectives inform our understanding of wealth and value in science, technology, engineering, and mathematics (STEM) learning? The purpose of this chapter is to explore various forms of currency under exchange within STEM education contexts in order to shed light on this question. Sociocultural theories facilitate broader understandings of these currencies – specifically by transcending traditional notions of currency as a monetary phenomenon to currency as language, skills, identity, and beyond. Through this extended metaphor, we gain a more comprehensive understanding of the wide range of impacts that high quality STEM education can have on students' scientific wealth.

The rest of this chapter proceeds as follows. I begin by exploring the nature of currency in cultivating students' scientific wealth. This discussion is useful in situating how economic currencies have traditionally undergirded national motivations for developing robust STEM education. It is in this context that I highlight important historical milestones – such as WWII and the 1960s Space Race – that signify initial STEM education development as a primarily economic endeavor. The third section explores the emergence of sociocultural theories as a response to previous STEM education research trends. I highlight how sociocultural research informs pedagogical practices that develop shared currencies within STEM education spaces. The chapter concludes by offering currencies for the future. Throughout the chapter, I introduce both personal and student narratives in order to ground this work in the lived experiences of STEM learners. I hope this chapter is as enlightening for readers as it was for me to write it.

What is Currency? What is Scientific Wealth?

Merriam-Webster (n.d.) defines currency as “something customarily and legally used as a medium of exchange” or “a measure of value”. The term currency typically invokes a monetary meaning. Nations establish currencies through which individuals partake in monetary transactions. In the United States, individuals trade and exchange via the U.S. dollar. Even among paradigms where currency invokes a monetary meaning, there are a plethora of examples in which this narrow definition does not account for all exchanges. For example, roughly 48 million individuals serve as unpaid caregivers in the United States (Kasten, 2021). Transcending this traditional definition of currency, many cultural artifacts – such as art, language, and food – are also valuable forms of currency that contribute

to the wealth and wellbeing of a community. For example, studies have shown that individuals who engage in artistic leisure activities experience improved life satisfaction (Bhatnagar & Imran, 2024; Hand, 2018; Lee & Heo, 2021). In STEM education, valued currencies refer both to the monetary gains afforded to individuals pursuing STEM careers and economic growth experienced by national investment in competitive STEM industries. While it is important to understand these dynamics, we can and should expand our notion of currency to recognize diverse modes of exchange between individuals engaged in STEM learning.

We can draw from Indigenous scientific scholarship in order to push our understanding of currency beyond its monetary connotation in STEM fields. Botanist and author Robin Wall Kimmerer (2013, 2024) explores how Indigenous cultures engage in scientific ways of knowing by learning the wisdom of other species. She situates this discussion within the context of the work of her graduate student – Laurie. Laurie harvests sweetgrass in order to determine whether human interaction with the plant promotes growth. Laurie found that human interactions with sweetgrass did spurn growth while neglect led to demise – a finding contrary to scientists’ Western objectivist-oriented expectations. Similarly, native Canadians cultivate scientific knowledge by “building holistic pictures of the environment by considering a large number of variables qualitatively” (Berkes, 2009, p. 154). In these examples, scientists and the environment shared the currency of symbiosis. In her recent book, *The Serviceberry*, Kimmerer (2024) further highlights how gratitude is a primary currency of the gift economy – the marketplace of reciprocity between humans and the natural world.

Building on these traditions, we see additional currencies worthy of exploration in STEM contexts. These currencies are characterized by the skills, language, and identity that are unique to STEM learners. With respect to scientific skills, scientists utilize critical thinking, experimental reasoning, and data analysis to formulate scientific claims. A shared language develops as science practitioners work to share these claims with colleagues and the public. It is through this continual process that individuals’ science identity develops – just as my high school self and peers endeavored in a process of identity-building that propelled us all to enter scientific degree programs.

Individuals cultivate scientific wealth through participation in these various modes of exchange. I define *scientific wealth* as a science learner’s gains accrued from engaging in authentic, high-impact scientific practices. In the classroom, learners create scientific wealth through peer engagement,

scientific practice, and enjoyment of their work. In the next two sections, I further detail how these currencies undergird STEM education, starting first from its economic origins and then its sociocultural traditions.

Economic Currencies: STEM Education Origins

In this section, we embark on a brief journey through key milestones in the growth of STEM education in order to understand the economic currencies underpinning its development. History shows us that there are always multiple perspectives in examining any event. I acknowledge that I can only tell a partial history – one that will undoubtedly omit some important details. Also, my discussion in this section concentrates on formal STEM education milestones. Individuals have been engaged in science learning since the dawn of human existence. Our evolutionary ancestors' musings with fire are likely our first encounter with STEM learning. The full history of this topic would take many book volumes, let alone one section of one chapter of one book. I choose to discuss a few historical examples that illustrate the origins of STEM education as a primarily economic endeavor.

I choose to offer the passage of the Morrill Acts (1862, 1890) as the formal beginning of STEM education in the United States. These Acts made it possible for states to establish public colleges and universities funded through the sale of federal lands (National Archives and Records Administration [NARA], 2022). These lands were almost exclusively taken from Native American tribal holdings – yet another problematic legacy for STEM education. Prominent institutions founded under these Acts include Cornell University, Ohio State University, and Texas A&M University. The focus of these institutions was to teach students (almost all white men) to become proficient in the agricultural and mechanical arts sectors – laying the foundation for modern engineering education (NARA, 2022). The second Morrill Act (1890) initiated many historically Black colleges and universities – providing valuable educational opportunities for African Americans after the Civil War. These initial developments underscore the original purpose of STEM education to be to cultivate a more economically robust agricultural industry.

The early to mid-twentieth century saw tremendous scientific advancements and accompanying growth of STEM education – driven significantly by international conflict. World War I marked a new age of global technological prowess, and unfortunately, that resulted in devastating consequences. The German forces' use of the newly devised mustard gas made soldiers the first experimental subjects of the chemical agent (Rall &

Pechura, 2000). On the US homefront, young women continually ingested carcinogenic radium-infused paint as they painted dials and other war machinery with the luminescent substance (Moore, 2017). World War II saw further escalation of these themes – most visible through the US atomic energy testing in the Marshall Islands and the eventual explosion of the atomic bomb on the residents of Hiroshima and Nagasaki in 1945 (Simon, 1997). As WWII ended, the US government engaged Operation Paperclip – a secret operation that brought 1600 German and Austrian engineers to the United States for research and development purposes (Neufeld, 2023).

In the United States, the national emphasis on STEM education skyrocketed (literally and figuratively) during the Cold War (Neal et al., 2008; Rudolph, 2002; Vossoughi et al., 2018). In 1950, the federal government established the National Science Foundation (NSF) for the purposes of promoting scientific research and STEM education (National Science Foundation Act, 1950). In a recent review, Lopez and de Mattos (2024) analyze Cold War-era government reports on science education. During this era, two themes emerged from this analysis. First, science education was a vehicle for economic progress. This goal was reflected in Executive Order 10521 – signed by President Eisenhower to expand NSF programs:

“The National Science Foundation has been established by law for the purpose, among others, of developing and encouraging the pursuit of an appropriate and effective national policy for the promotion of basic research and education in the sciences” (USA, 1954, p. 1499).

Second, science education was a mechanism for national security. The launch of Sputnik I by the Soviet Union triggered anxieties within the United States government that the Soviet science education was more effective than US STEM programs (Lopez & de Mattos, 2024). The subsequent “Space Race” saw the United States and Soviet Union engaged in a rivalry over which nation (and consequently which political system) produced the most talented scientists and engineers (Neal et al., 2008). At the head of the US space program was Wernher von Braun – a German-born aerospace engineer who was secretly moved to the United States during Operation Paperclip (Neufeld, 2019). Prior to his extraction, von Braun was an active member of the Nazi Party.

The historical milestones discussed above all position financial and national gains as the primary objective for STEM education – oftentimes at the expense of the individuals involved in the scientific processes and

with flexible adherence to ethics. While the professional science practice has come a long way from the overt brutality of the early twentieth century, the economic perspectives for STEM development are still prominent today. For example, Robert May (1997) discusses measures of nations' scientific productivity in *The Scientific Wealth of Nations*. This includes percent of GDP spent on scientific research and development (R&D) and the quantity of scientific paper publications and accompanying citations. These metrics represent traditional benchmarks through which the impact of STEM fields is quantified today. While economic perspectives are quite informative about the global landscape of professional science – I venture that there are other ways of conceptualizing scientific wealth. In the next section, I utilize four tenets of sociocultural theories to shed light on the currencies under exchange within STEM education and how these currencies contribute to shaping learners' scientific wealth.

Sociocultural Currencies: Skills, Identity, Language

STEM learners participate in currencies of exchange that cannot be made visible through economic perspectives alone. Sociocultural theories reveal valuable modes of currency – such as language, identity, and shared experience – that are under exchange within STEM education spaces. Likewise, we can take a historical lens to understand how these theories developed in response to paradigms of time.

Emerging in the 1970s from the work of Lev Vygotsky, sociocultural theories explore the role that culture and environment play in shaping learners' cognitive development (Mercadal, 2021; Wertsch, 1991). Sociocultural theories center students' activity both with and within their environment and are less focused on learners' mental models of key phenomena (Greeno, 1998; Nasir & Hand, 2006; Saxe, 1988). Sawyer (2005) reflects this sentiment when expressing that sociocultural theories see knowledge as “not just a static mental structure inside the learner's head; instead, knowing is a process that involves the person, tools, activities, and environment” (p. 5). While this chapter examines sociocultural theories from a science learning perspective, these theories transcend academic disciplines to highlight the role of culture in learning (Gregory et al., 2004). In this section, I review four key tenets of sociocultural theories in science learning (Nasir & Hand, 2006). These tenets are:

Culture and activity constitute primary units of analysis within sociocultural research and practice.

The process of science learning renegotiates learners' personal and communal identities.

Cultural tools and artifacts mediate science learning

Science learning occurs at multiple levels

For each tenet, I describe accompanying pedagogical approaches that are valuable in fostering students' scientific wealth.

Tenet #1: A Focus on Culture and Activity

The first core tenet of sociocultural theories is a focus on students' culture and activity (Brown et al., 1989; John-Steiner & Mahn, 1996; Nasir et al., 2006; Saxe, 1998; Saxe et al., 1999; Srinivasa et al., 2022). Greeno (1996) describes activity as the "continual negotiation of people with each other and with the resources of their environments" (p. 9). Any activity is then affected by its surrounding social, historical, and cultural influences (Nasir & Hand, 2006). Additionally, students co-produce knowledge through activity (Brown et al., 1989). Thus, culture and activity are important currencies that both form and are formed by science learning.

Situated learning theory provides much of the framework for studying student activity in STEM classrooms. A sub-genre of sociocultural theory – situated learning theory relies on the study of observable patterns and discourses in social interactions to understand how students make meaning during science learning (Brown et al., 1989). Brown and colleagues (1989) also explain that students should practice authentic tasks of a field to learn the "cumulative wisdom of the community" (p. 33). Authentic tasks can broadly be thought of as ordinary practices of a culture.

In STEM fields, authentic learning involves student engagement in practices characteristic of science disciplines. For example, argumentation is one core scientific activity (NGSS, 2013; Rapanta & Macagno, 2022) that trains students in the "scientific habits of mind" (Sampson et al., 2009, p. 47). Andriessen and Sawyer (2005) describe argumentation in the science education context as "a form of collaborative discussion in which both parties are working together to resolve an issue" (p. 443). Students learn that science is distinct from other disciplines through its intentional marshaling of evidence to support and justify claims (Allchin & Zempen, 2020). Wang (2020) employs situated learning theory to examine students' self-positioning during small group argumentation in a high school physics context. They find that students often defer decision-making to the perceived highest performing student during group work. This suggests that perceived status is another currency under negotiation amidst learning.

All STEM learning takes place within cultures – whether those of students'

prior backgrounds, classroom dynamics, or broader society (Ladson-Billings, 1995a). No matter their origin, these cultures are inextricably linked to students' learning and one another. Esmonde (2017) emphasizes this point when stating that students' culture is "inseparable from cognition" (p. 6). Therefore, STEM educators can embrace culturally relevant and responsive teaching and place-based education to enact this tenet.

Culturally relevant, responsive, and sustaining pedagogies (Brown-Jeffy & Cooper, 2011; Gay, 2018, Ladson-Billings, 1992, 1995b; Paris, 2012) integrate students' cultural backgrounds into instruction and learning processes. While the pedagogies share key characteristics, the terms are distinct. As the pioneer of culturally relevant pedagogy research, Gloria Ladson-Billings (1992, 1995, 2021) writes this teaching paradigm empowers students to "maintain their cultural integrity while succeeding academically" (p. 476). The integration of students' culture into learning is done explicitly in order to promote engagement and sense of belonging in the classroom. Gay (2015) expanded on this work to highlight one core premise of culturally responsive teaching – students both cannot and should not have to separate their school and home cultures in order to succeed academically (Erickson, 1997; Gay, 2015). In the last decade, culturally sustaining pedagogy has emerged as a means of fostering students' linguistic skills and multicultural identities as a core component of democratic schooling (Alim & Paris, 2017; Paris, 2012). These developments coincide with the growth of anti-deficit scholarship as a rebuttal to early research on students' "cultures of poverty" (Burt, 1959; Jensen, 1969). Ladson-Billings (1995), Gay (2015), and Paris (2012) encourage us to implement mechanisms for students' cultural engagement and goal-directed action in the classroom. This can involve students' participation in biographical or autobiographical writing (Payne et al., 2013; Schmidt, 1999), co-authorship of classroom expectations or norms (Candela, 2005), and family engagement in educational experiences (Goodman & Hooks, 2016). In an example of these approaches in action, Candela (2005) situates their work in a primary-level science classroom in Mexico City in order to study students' role in shaping institutional norms. She finds that students develop identities as "knowledgeable and responsible participants in classroom activities" as a result of organizing their own small group norms during a science task (p. 332). Candela (2005) highlights the metaphor of identity as a currency under exchange in classrooms – an idea that I expand upon in the next section.

Place-based education (PBE) is a second approach useful in fostering students' cultural currencies. Through PBE, we can connect students' learning

to the specific location in which it occurs and leverages its unique learning affordances (Habig & Gupta, 2021; Raja, 2024; Renshaw & Tooth, 2017; Vander Ark et al., 2020). PBE is also interdisciplinary and acknowledges the varied meanings that place holds for students, teachers, and community members (Demarest, 2014; Dunbar-Wallis et al., 2024). By capitalizing on the value of place in STEM learning, students exchange shared currencies of language and identity. Students also learn how the history of a place contributes to the current realities of the place and to community members' ongoing (re)constructions of the place identity. Kimmerer (2013) reflects this sentiment when stating, "to be native to a place we must learn to speak its language" (p. 48).

Existing scholarship offers insight into the myriads of ways that STEM educators can work to enact this tenet – and to detail them all is beyond the scope of this chapter. However, a few examples stand out due to their wide applicability. First, Johnson and Elliott (2020) emphasize that STEM educators should work to combat the stereotype that science is only performed in laboratories by white men in lab coats. Students' cultures are sustained when they learn about the scientific successes of individuals that share their cultural background (Young et al., 2019). In addition, science teaching through real-world problem solving can situate science concepts within students' lives and communities (Aceves and Orozco, 2014; Brown, 2021). In my hometown of Syracuse, NY, Dr. Nicole Fonger (2024) and local high school students investigate the adverse health impacts of the city's lead poisoning crisis, and ultimately, use their findings to advocate for reform. Educators' use of focal events or case studies – such as lead poisoning in Syracuse (Fonger, 2024) or increased rates of diabetes among Latino communities in south Texas (Montoya, 2011) – can make science material personal for students (Gilbert, 2006). Within these examples, students accrue self-efficacy as a component of their scientific wealth as a result of participating in such learning experiences.

Tenet #2: Science Learning Renegotiates Identity

The second tenet is that students' participation in science learning renegotiates their personal and community identities. Identity is an intricate social construct. Gee (2000) offers that an individual's identity is being a "certain kind of person" that embodies traits or actions of a specific group (p. 100). Even more broadly, identity refers to how individuals see themselves within given contexts as a result of participation in certain roles and communities (Lemke, 2001; Stets & Burke, 2000). Thus, individuals can hold multiple identities that fluctuate in salience as they develop new

interests, take on new roles, and evolve in their relationship with others (Carlsson, 2015; Jones & McEwen, 2000).

One core venue through which individuals develop these identities are various communities of practice. Lave and Wenger (1991) define communities of practice as “a set of relations among persons, activity, and the world” (p. 98) that evolve as experienced learners enculturate novices to the beliefs, skills, and characteristics of the community. Experienced learners act as “agents of change” when they facilitate the movement of novices from a state of “legitimate peripheral participation” to full participation (p. 37). Lave and Wenger (1991) deem this process cognitive apprenticeship. This concept draws from Vygotsky’s (1978) zone of proximal development in that it juxtaposes learners’ current level of knowledge with their future level of knowledge after assistance from critical others. Individuals’ transition to full participation involves their self-concept being aligned with the type of person who participates in a community as well as recognition from meaningful others as members of a community. Thus, students’ simultaneous internal and external recognition constitute their identity (Gee, 2000). Over time, students’ participation in communities of practice affect their goal orientations and interests in those fields (Eckert, 1990; Belenky et al., 1997). We see that identity is yet another currency under exchange via cognitive apprenticeship.

Cognitive apprenticeship and identity work have much to offer science educators and researchers. Driver and colleagues (1994) emphasize that to learn science means to enter the science community. Thus, we can design authentic learning experiences that engage students in the currencies of skill- and identity-building within shared communities of practice. One mechanism could be through exposing students to scientific role models (Ovid et al., 2023; Shin et al., 2016). Scientific role models not only show students the characteristic behaviors of scientists but also serve as “representations of the possible” (Morgenroth et al., 2015, p. 467). For students, this representation emphasizes that they are also members of the scientific community.

From a research perspective, the notion of cognitive apprenticeship directs us to explore the ways in which students receive recognition from meaningful others during their enculturation process. A primary venue for this process is through mentorship programs and research experiences. These experiences enculturate students to the scientific discipline while also heightening their science identity and self-efficacy (Atkins et al., 2020; Robnett et al., 2015). For example, Atkins and colleagues (2020)

use thematic analysis to understand students' science identity development as a result of receiving mentorship. The authors find that students benefit from shared identity mentorship – meaning that their mentor shares similar characteristics (i.e. gender, values) as the student. Mentors not only provide valuable reinforcement of students' science identity, but they also facilitate opportunities for students' advancement in STEM fields (Mondisa & McComb, 2015). In addition, course-based research experiences have shown promise in promoting science identity among underrepresented students in STEM, which contribute to their scientific wealth (Atkins et al., 2020; Camacho et al., 2021; Vasquez-Salgado et al., 2023). The notion of cognitive apprenticeship is so essential to sociocultural theory that it undergirds the following two tenets.

Tenet #3: Cultural Tools and Artifacts Mediate Science Learning

Sociocultural theories recognize the role of cultural tools and artifacts in shaping science learning (Brown et al., 1989; Mercadal, 2021; Robbins, 2005; Saxe, 1988; Sawyer, 2005; Wertsch, 1991). Such tools and artifacts may include the physical objects – such as lab equipment, technological systems, or specimens – that students encounter during learning. However, the notion of cultural tools can be expanded beyond the physical realm to include students' conceptual knowledge, mnemonics or acronyms, and collective memories employed throughout the learning process. Sainsbury and Walker (2011) liken scientific concepts to discourse tools that students employ during learning. Situated learning and activity theories emphasize that these tools can only be truly understood through their use, which further reinforces the importance of studying students' learning in context (Brown et al., 1989; Wertsch, 1991; Wertsch et al., 1995). Through interaction with both physical (i.e. lab equipment, computers) and mental (i.e. acronyms) tools, science learners exchange currencies of shared language and skills.

Sociocultural theories shed light on the valuable currency of language in STEM learning – a development that Lemke (2001) classifies as the “linguistic turn” in the field. In sociocultural theories, language serves as the mediator between individuals' cognitive and social functions (Luria, 1981; Pereira, 2022; Wertsch, 1998). Nasir and Hand (2006) reflect this sentiment when they write that “language serves a dual role in human functioning: it is a communication tool, and it mediates human mental action” (p. 461). Likewise, Olson (1995) dubs language learning as an acquisition of “the folkways of culture” (p. 95).

In STEM education spaces, language is a currency through which students make meaning of science concepts and develop scientific skills. Through this process, students accrue scientific wealth. More specifically, students' use of tools as currency – especially language – usher in the conceptual change necessary to promote students' learning.

Conceptual change is the process through which students modify their knowledge and beliefs as a result of new experiences (Posner et al., 1982). From a sociocultural perspective, Kelly et al. (1998) view conceptual change as “an over-time process in which novice candidates to particular social groups gain entry by adopting the language, argumentation strategies, and reasoning processes of the group” (p. 852). Thus, science learners also enter scientific communities of practice through gaining proficiency in *scientific language*. Kelly and colleagues (1998) focus on argumentation because it is simultaneously a language tool and a scientific skill – a mutual condition that makes it especially relevant for this section's discussion of language and skill currencies. In the physics classroom, these authors study students' conceptual change related to electricity. To achieve a more robust assessment of students' conceptual change (Lazarowitz & Tamir, 1994), the authors employed an argumentation-focused performance assessment with the use of physical manipulatives as tools. Jimenez-Aleixandre and colleagues (2005) also find that the most impactful argumentation tasks enact the sociocultural tenets of learning through tools and communal problem-solving. In a recent meta-analysis, Bodnar and colleagues (2016) highlight how games can serve as an important teaching tool in undergraduate engineering education. Students' interaction with tools constitutes yet another currency under exchange in STEM classrooms. Additionally, all of these authors show that sociocultural engagement with tools are crucial to promoting deep and deliberate belief change (Chinn & Brewer, 1993; Hatano & Inagaki, 2003) – a prerequisite to students' movement into communities of practice.

Tenet #4: Learning Occurs at Multiple Levels

Sociocultural theories' fourth tenet is that student learning occurs on multiple levels simultaneously. Nasir and Hand (2006) provide a concise overview of different interpretations on these levels of development – specifically highlighting the work of Vygotsky (1978) and Rogoff (1995). In *Mind and Society* (1978), Vygotsky distinguishes between interpersonal and intrapersonal processes. He discusses how all individual learned processes begin in response to an external activity and then are transformed into an internal activity through repeated events – a process that he deems internalization. Internalization is a primarily sociocultural process as it is

both “socially rooted” and “historically developed” (Vygotsky, 1978, p. 57).

Barbara Rogoff (1995) advances this discussion by situating learner development along the personal, interpersonal, and communal planes. In her work, these planes refer to participatory appropriation, guided participation, and apprenticeship, respectively. Participatory appropriation is the process through which individuals transform their knowledge through their own participation in activities. While similar to Vygotsky’s (1978) notion of internalization, Rogoff (1995) challenges the term as advancing a “static” or strictly “acquisitional” portrayal of individuals’ internal construction of knowledge. Rather, participatory appropriation allows for a more fluid understanding of individuals’ cognitive participation. A participatory appropriation approach can be useful to study students’ science identity – specifically revealing how students respond to external recognition during the process of their identity construction. I began this chapter with an anecdote about my science identity development as a participant in Science Olympiad, which was an experience best studied through Rogoff’s (2005) participatory appropriation lens.

Guided participation refers to individuals’ mutual involvement in learning endeavors. At this level, Rogoff (1995) stresses the importance of studying how learners coordinate their efforts to accomplish shared goals. Much of the cooperative learning and student positioning research are driven by this interest. For example, Wieselmann and colleagues (2020) use a case study approach to investigate the small group interactions of fifth grade students during an engineering task. Not only do the authors find that boys and girls take on distinct roles within the group task, but comments from girl students are more often to go unacknowledged by the group. Campbell and Hodges (2020) use a similar method to compare the “patterns of participation” of middle school and university students studying mathematics. The authors identified five key patterns in this process: *confirming one group member* (supporting group members were satisfied with the quickest solution path posed by group leader), *competing strategies* (group members competed in their problem-solving and were unwilling to negotiate a shared solution), *free-for-all* (group members shared solutions with disinterest towards others’ contributions), *co-construction* (group members collaboratively and productively worked towards a solution), and *two member collaboration* (two group members worked collaboratively while a third observed passively). These patterns were observed among samples of middle level and university students and lend further credence to the recommendation that instructors set the classroom norms early to be of productive collaboration and problem-

solving (Boaler, 2008; Wang, 2020).

Lastly, apprenticeship constitutes patterns of activity in the communal plane (Rogoff, 1995). Drawing from Lave and Wenger's (1991) idea of cognitive apprenticeship, Rogoff (1995) furthers the notion of apprenticeship beyond the study of "expert-novice dyads" to include "systems of interpersonal involvements around culturally organized activity" (p. 143). It is on the communal plane that learners exchange the currency of collective remembering – an action-oriented process in fostering collective memory (Wertsch, 2009).

Collective memory brings together the collection of individual memories in a space such that the individual feels "in the world" of an academic discipline (Hirst & Manier, 2008, p. 183). Another perspective sees collective memory as the socially constructed "realities of the past" (Irwin-Zarecka, 1994, p. 54) set "not within the minds of individuals but in the resources they share" (Irwin-Zarecka, 1994, p. 4). These definitions reveal how the established culture of the scientific fields can impact how the students of today navigate the discipline. We must acknowledge that the history of professional science and science education is deeply embedded and influenced within the culture of the time. Throughout history, we see that professional science embodied racism, sexism, ableism, and many other forms of oppression while simultaneously pushing boundaries of scientific knowledge. So, how does this collective memory impact the students of today? What does it mean for medical students to be studying medical textbooks whose past publishers capitalized on the practice of grave robbing for education (Schultz, 2005)? Or how do we reckon with some Americans' distrust of vaccine science when our nation's scientists and government officials experimented on Black bodies during the Tuskegee Syphilis Study (Brandt, 1978)? Or how do college students with disabilities engage in science classrooms knowing the history of forced sterilization as permitted by the U.S. Supreme Court in *Buck v. Bell* (1927) (Lombardo, 2022)? To ignore these questions is to ignore history. Thus, we must advance inclusive and honest history of science teachings for all STEM students in order to be true to our commitment for equity in science.

Collective memory is also a prevalent currency within the scientific history of place. Recall, Kimmerer (2013) discusses the indigenous biological knowledge that harvesting sweetgrass promotes growth of the plant – a tradition grounded in the learned knowledge of the community over time. Beyond its effect on scientific knowledge, collective remembering influences

communities' attitudes towards science. For example, the 1986 Chernobyl nuclear power plant disaster has long embedded itself within the collective memory of the nations affected by the event and has impacted communities' attitudes towards nuclear power (Dudchik & Fabrikant, 2012; Hannam & Yankovska, 2017; Kalmbach, 2013). In the United States, scholars have highlighted how the racist and ableist legacy of the eugenics movement is still visible through the previously discussed "cultures of poverty" research paradigms and through commitment to a culture of high-stakes testing (Stoskopf, 2002; Jackson & Warren, 2023; Winfield, 2012).

Currencies Made Visible

This section explored how sociocultural perspectives illuminate the various currencies under exchange within STEM classrooms. Such valuable currencies include culture and identity – not only because of their effects on learners but also because they are constantly being reshaped during learning. Students' identities are (re)defined in response to social influences. For example, students' recognition as a "science person" from family and teachers contributes to their science identity, which refers to their sense of self as a scientist (Carlone & Johnson, 2007). Students' integration of this external recognition into their self-concept reflects Vygotsky's (1978) notion of internalization. Scientific skills are another form of currency. I have reviewed several important scientific skills in this chapter – such as argumentation, critical thinking, and experimentation – although there are undoubtedly many skills that I have omitted. It is through engaging with these skills that science learners become enculturated to communities of practice (Lave & Wenger, 1991). Lastly, language is perhaps the most vital currency as it mediates all other forms of action and communication during learning (Luria, 1981). For example, it would be an oversight to study students' scientific argumentation as a skill-building without acknowledging the role that language plays in cultivating this skill. Language is also the vehicle through which the currency of collective memory is shared between individuals and across generations. As Wertsch (1991) offers, we are able to free ourselves from unwanted traditions and patterns when we recognize the power of language for positive change. To do this, we can also immerse ourselves in learning the teachings of our collective memory. Collective memory, specifically, can reveal cultural norms of a discipline. In professional science, we see that the historical memory of the discipline is marred with both significant scientific advancements but also immense social injustices. We reckon with both when we exchange the currency of memory. All of the currencies summarized above help learners accrue scientific wealth and work towards science knowledge and social betterment.

This chapter introduced the concept of sociocultural currencies and scientific wealth for a few reasons. Most directly, I utilized these metaphors to challenge traditional historical motivations for development of robust and competitive STEM education. This was not done to cast aside economic perspectives entirely, nor to discount the numerous financial motivations that incentivize college students to pursue STEM degrees and careers. Rather, it was my intention that these metaphors also celebrate how students' access to high-quality STEM education can serve them in unique ways. Put another way, STEM education is a compelling venue for students' character-building, skill development, cultural growth, and other forms of learning. While all of these diverse goals may not have been front-and-center throughout history, I believe that STEM education would benefit from leaning into its sociocultural offerings. And this is not just my opinion – STEM education research bears this out. Students' science engagement increases when their science education experiences integrate their cultural backgrounds into learning (Madkins & Nasir, 2019; Stevens et al., 2016), promote real-world applications of content knowledge (Li et al., 2025; Mebert et al., 2020; Parsons & Taylor, 2011), and emphasize communal goals (Allen et al., 2015; Clark et al., 2016; Diekman & Steinberg, 2013; Nalipay et al., 2024; Vesterinen et al., 2016).

Currencies for the Future

It is my hope that this chapter has provided a fruitful overview of the diverse currencies under exchange within STEM learning spaces. By participating in the marketplace that is STEM education, learners enhance their scientific wealth – a feature characteristic among participants in scientific communities of practice. As is the case for most scientists, my work in writing this chapter has uncovered many more questions. Personally, I am intrigued by the notion of currencies of the future. That is, what are aspects of scientific wealth that remain unexplored? How can these currencies serve us moving forward?

Sterling (2010) writes that STEM education should be “fully responsive to the conditions and needs of our time” (p. 105). Our time has put the scientific enterprise at a critical juncture. In the United States, a growing number of individuals say that they distrust scientists (Tyson & Kennedy, 2024). A recent study found that only one-third of Americans are considered scientifically literate (Miller et al., 2024). Additionally, scientists are experiencing heightened anxiety around the future of grants and other research funds. To meet Sterling's (2010) challenge, we need to crystallize our intentions for science education. To do so, I ask us to consider: what are

the intangible traits that can unite all science learners amidst a period of unprecedented division? I cannot begin to offer a comprehensive response for this question, but I believe that we can extend the currency metaphor and previous research into the future.

Criticality is one important currency for the future. As a core component of her Historically Response Literacy (HRL) framework, scholar Gholdy Muhammad (2020) offers a definition of criticality as “the capacity to read, write, and think in ways of understanding power, privilege, social justice, and oppression” (p. 120). Muhammad (2020) views the teaching of criticality to a learning pursuit – one that is ongoing in its “study of the state of humanity” (p. 132). Moving forward, students must develop criticality – not only better analyze the world around them but also advocate for themselves and their communities (Beck, 2005; Ginwright & James, 2002). In STEM classrooms, criticality can be cultivated by teaching through a socioscientific issues lens. As I alluded to in discussing the first sociocultural tenet, socioscientific issues (SSIs) are highly salient social challenges that explicitly connect to science (Ewing & Sadler, 2020; Sadler, 2004; Zeidler et al., 2019; Zeidler & Nichols, 2009). SSIs are grounded in sociocultural theories because they acknowledge that the nature of controversial issues varies across context (Zeidler et al., 2019). Many socioscientific issues – from hydrofracking to climate change to genetically modified organisms (GMOs) – offer educators a direct opportunity to foster students’ criticality. Additionally, Sadler (2009) calls for “the development of communities of practice in science classrooms that prioritize socioscientific discourses and development of identities reflective of engaged citizenship” (p. 12). To advance criticality as an important currency in STEM education, we should afford students the opportunity to see how science can solve pressing issues of our time, and ultimately, advance the public good.

Additionally, we should celebrate the ways that STEM students are already demonstrating criticality and social justice orientations upon entering college. Many college students – especially those from historically excluded backgrounds in STEM – demonstrate criticality when asked why they chose to pursue a STEM degree (Herrera & Kovats Sanchez, 2022; Jaumot-Pascual et al., 2023a, 2023b; Smith et al., 2014). For example, women of color in graduate engineering programs conceptualize giving back to their community through role-modeling, mentoring others, and creating counterspaces (Jaumot-Pascual et al., 2023b). A counterspace is a space in which individuals from marginalized groups resist oppressive structures (Case & Hunter, 2012). Counterspaces maintain an oppression narrative referring to individuals’

personal relationships to the oppressive structure, and a resistance narrative focusing on how individuals demonstrate competence and strength in overcoming oppression (Case & Hunter, 2012). In STEM, counterspaces are valuable forms of resistance against a field that has historically excluded students from ethnic minority backgrounds. Students resist this exclusion by using their science education to restore justice for their communities. For Indigenous students, this may manifest through intentions to preserve tribal sovereignty such as efforts to expand broadband internet or improved health care access (Jaumot-Pascual et al., 2023a). Or, low-income students maintain a desire to bring financial stability to themselves and their family, but also acknowledge larger personal goals in the process (Madsen et al., 2023) As one student – Devon – stated:

“We [STEM students] want to get out and make money. I think that’s the main goal with engineering ... but obviously success is not measured through wealth. That’s not something I personally believe in. I think it’s just like if I can find something and enjoy doing it every day, I consider myself successful. I think it just so happens that what I’m interested in also is financially fairly stable and fairly future proof, but I think that’s just a coincidence” (Madsen et al., 2023, p. 10)

Students’ personal backgrounds shape their motivations to pursue STEM education and listening to these personal stories are essential to our endeavors to support students in their STEM degree path. We need to remember that students are the experts on their own lived experiences – a key component of culturally responsive and sustaining pedagogies (Gay 2015, 2018; Ladson-Billings, 2021; Paris, 2012). And it is through guided participation that we, as educators and researchers, become more adept at supporting and advocating for them. Thus, criticality is a currency through which students can not only change themselves and their communities for the better but also challenge notions of who is the “expert” and “learner” in STEM education classrooms.

Second, empathy affords us the ability to connect with fellow science learners and expand our notions of science for societal advancement. For example, Nalipay and colleagues (2024) explored students’ STEM persistence intentions within a STEM service-learning context in Hong Kong. Using structural equation modelling, they find that students’ sense of empathy and engaged citizenship predicts their persistence intentions in STEM. Likewise, Guney and Seker (2012) highlight how promoting students’ empathy allowed students to connect science content to broader societal trends even in a

high school physics lesson, which resulted in higher student interest in the content and improved nature of science beliefs. Empathy also expands our ability to both address and solve scientific problems. It is a misnomer to say that science is “value-free” or “completely objective”, because our values and other passions are visible in the problems we choose to solve, and what problems we deem worthy of our time and effort. While we still rigorously apply the scientific method, we nonetheless make personal judgments throughout the scientific process. Thus, our support for individuals’ empathy as students and future scientists will reinforce their initiative to solve new problems that address previously overshadowed communities and issues. This is visible in my hometown of Syracuse, NY. As I mentioned previously, we have a group of local high school students studying negative health impacts of the city’s lead poisoning crisis. While not all of these students are likely to be adversely affected by not participating in this project, it is their empathy for their fellow students and identity as a Syracusan that motivates their involvement and keeps them engaged throughout. A similar project revealed the extent of water pollution in nearby Onondaga Lake, which was caused by improper waste disposal during industrial urban development. For decades, this lake was the most polluted lake in the United States (Molnar, 2024) – a title made even more unjust given its naming and close proximity to the native Onondaga Nation. A group of activists within the Onondaga Nation were instrumental to initiating lake cleanup efforts. These case studies and accompanying literature show us that cultivating students’ empathy and knowledge of community can not only support learning but also advance social betterment.

The final vital currency for the future of STEM is that of joy. While hard to define, Brunsell & Fleming (2014) classify joy as “something that we know when we see it” (p. 1). Also serving as the fifth component of Muhammad’s (2020) HRL framework, joy reaffirms our participation and identities as science learners. Anggoro and colleagues (2017) find that joyful science learning supports elementary-aged students’ attitudes towards science. While much of the research has occurred in the elementary-level context (Cronqvist, 2021; Vartiainen & Aksela, 2013), joyful science learning need not stay relegated to this demographic of learners. We can bring the currency of joy to all levels of STEM education, because we never age out of finding joy in ourselves and our surroundings. Why would we engage in lifelong learning if we did not find joy in the process? Why would we do anything if we did not enjoy it – at least to some degree? Personally, I would not have continued with an undergraduate physics degree if I had not found joy in the communal experiences through the Science Olympiad organization in high school, nor

in the college experiences of continued volunteering with that organization, nor without the support and recognition from my undergraduate peers and advisors. Amidst this current period of uncertainty in science, we can benefit from refocusing on the experiences that sparked our interest and curiosity in science in the first place. When we center these scientific experiences, the currencies under exchange during them, and the people we met in the process – we reaffirm what it means to be a science learner. Not only that, but we reestablish our dedication to advancing equitable science learning, both as a learner and teacher of science. It is through these commitments that we demonstrate our collective scientific wealth.

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