Chapter 4
STEM Education as a Meta-discipline

Teresa J. Kennedy and Michael R. L. Odell

Abstract STEM education has evolved into a meta-discipline, an integrated effort that removes the traditional barriers between the subjects of science, technology, engineering and mathematics, and focuses on innovation and the applied process of designing solutions to complex contextual problems. Stakeholders including schools, community organizations and businesses acknowledge the fundamental links between economic prosperity, knowledge-intensive jobs dependent on science and technology, and the importance of building a culture of continued innovation aimed at addressing current societal problems and those of the future. STEM education provides students with the knowledge and skills that they need to be successful in the twenty-first century. This chapter explores STEM as a meta-discipline, discusses the origins and emergence of STEM education, as well as the differences between S.T.E.M and STEM, and the many variations of the acronym. STEM education policy development in countries around the world, definitions of STEM literacy, and pedagogical implementation models are also described.

Keywords Science · Technology · Engineering · Mathematics · STEM · STEM education · Interdisciplinary frameworks · Science pedagogy · PISA · Twenty-first century skills

Introduction

Over the last 25 years, significant funding, research, and development have focused on STEM education on a global scale. What is STEM education? STEM is the acronym for the subject areas of science, technology, engineering and mathematics (STEM). These four STEM umbrella disciplines are deemed by governments,

T. J. Kennedy (✉) · M. R. L. Odell
The University of Texas, Tyler, TX, USA
e-mail: tkennedy@uttyler.edu; modell@uttyer.edu

B. Akpan et al. (eds.), *Contemporary Issues in Science and Technology Education*, Contemporary Trends and Issues in Science Education 56,
https://doi.org/10.1007/978-3-031-24259-5_4

business and industry, and educators as essential to the global economy, competitiveness in the workforce, and in education. STEM disciplines "typically include educational activities across all grade levels—from pre-school to post-doctorate—in both formal (e.g., classrooms) and informal (e.g., after-school programs) settings" (Gonzalez & Kuenzi, 2012, p. 2).

Many different teaching approaches have been implemented to improve student learning in STEM disciplines. For example, numerous educators have employed project-, problem-, and/or phenomenon-based learning activities that require knowledge and skill application in specific areas, such as engineering. In addition, extracurricular activities are offered, such as team competitions encouraging student collaboration (e.g., solving a problem or apply coding and engineering principles to design and build robots). In these situations, students are typically afforded time with professionals in STEM fields (e.g., teachers organize guest lectures by STEM experts; STEM professionals provide feedback on class projects and/or serve as science fair judges providing feedback on student innovations; local companies provide students with organized opportunities to job-shadow and work as interns; etc.).

STEM educational opportunities also extend beyond the school classroom environment, occurring at home, in other venues such as the wide genre of museums, and during leisure time in the learners' communities (Kennedy & Tunnicliffe, 2022, p. 12). STEM-focused initiatives are intentionally planned and implemented around the world in a variety of settings by stakeholders such as schools, community organizations, and businesses as a way of building interest and fostering a diverse STEM workforce. These stakeholders acknowledge the fundamental links between economic prosperity, knowledge-intensive jobs dependent on science and technology, and the importance of building a culture of continued innovation aimed at addressing current societal problems and those of the future; since the reality is that there will undoubtedly be jobs that will be necessary in the future that do not exist today.

STEM education, as a meta-discipline, marks an integrated effort to remove the traditional barriers between the content areas of science, technology, engineering and mathematics, and focuses on innovation and the applied process of designing solutions to complex contextual problems. Using current tools and technologies, STEM education challenges students of all ages to innovate and invent, while promoting problem-solving and critical thinking skills that can be applied to their academic as well as everyday lives.

Scientific inquiry generally involves the formulation of a question that can be answered through *investigation*, while engineering design involves the formulation of a problem that can be solved through *design*. STEM education naturally brings these two concepts—investigation and design—together through all four disciplines (Kennedy & Odell, 2014, p. 247). However, STEM as a discipline was not always referred to as 'STEM'. There have been various acronyms, such as SMET, the first U.S. reference created in 2001 by the National Science Foundation (NSF), which referenced the standards that educators should follow, including the U.S. Next Generation Science Standards (NGSS Lead States, 2013) when teaching science, mathematics, engineering, and technology to K–12 students (ages 5–18), along with the inherent skills of analytical thinking, problem-solving and science competencies. NSF rearranged the order of the disciplines to form the acronym STEM later that same year, and many different iterations of the acronym have been created and implemented by countries across the globe. Examples of acronyms utilized will be discussed at length in a later section of this chapter.

Historical and Theoretical Background

One can argue as to the origins and emergence of STEM education. History relates the pioneering efforts of ancient Egyptians and Greeks, along with many others from around the world, who introduced and implemented different aspects of the field of science, establishing the importance of conducting investigations directly involving one's environment through efforts to make sense of their world and gathering evidence to support in-depth understandings. Examples include Ibn al-Haytham (Islamic medieval mathematician and astronomer who paved the way for the modern science of physical optics), Moustafa Mosharafa (the Egyptian theoretical physicist who contributed to the development of Einstein's quantum theory), the physician Hippocrates (known as the father of modern medicine), Aristotle (the inventor of the field of formal logic who identified the various scientific disciplines and further explored the diverse relationships between them), Thales (the infamous mathematician and astronomer who first investigated the basic principles, questioning the originating substances of matter), Empedocles (the philosopher known for a view of matter composed of the four elements of fire, air, water, and Earth), the Turkish astronomer Anaximander (who studied topics related to the fields we now refer to as geography and biology), and of course the study of mathematics by the Pythagoreans.

The concept of engineering has also existed since ancient times, as documented by structures such as the Leshan Giant Buddha and the Great Wall of China, the Chand Baori of India, the underground churches of Lalibela in Ethiopia, the Parthenon in Greece, the Roman Colosseum in Italy, the Aqueduct of Segovia in Spain, The Lost City of Mohenjo Daro in Pakistan, the Egyptian Pyramids and the Teotihuacan Pyramids of Mexico, along with many other UNESCO World Heritage sites such as Machu Picchu in Peru, all renowned as buildings that incorporate sophisticated astronomical alignments.

Science and mathematics have always been an essential part of the curriculum, dating back well into the last two centuries, especially at the university level where subjects such as agricultural science had a direct impact on workforce needs prevalent in society. The case can also be made that the modern STEM curriculum was partially a response to World War II and the need for innovations, medicine, and weapons. STEM overtly emerged during the Cold War with the launch of the Russian satellite, Sputnik. The U.S. government, in response to Sputnik, invested heavily in K–12 science and mathematics education with the goal of building a STEM workforce to support national security and the Space Race.

After the Cold War, STEM emerged as a driving factor of economic competitiveness in the global workforce. As the global economy became more interdependent, STEM education became a focus in most countries worldwide. For example, from 2000–2010, STEM jobs in the United States grew at a rate three times greater than other occupations. Due to the shortage of STEM professionals globally, policies have been instituted to increase the STEM pipeline in education and expand the diversity of the workforce, by creating educational programming targeting under-represented groups including minorities and women. For more information, see Chap. 10, which discusses gender and equity in science and technology education in the context of education for sustainable development.

STEM education and research are necessary requirements for a nation's development, productivity, competitiveness, and societal wellbeing (Marginson et al., 2013). Evidence that this is the case can be found in government efforts worldwide to improve STEM education at all levels—primary, secondary, and tertiary.

STEM education plays an increasingly important role in countries' economic wellbeing and global competitiveness. The Organisation for Economic Co-operation and Development (OECD) ranks achievement by country in mathematics and science using the Program for International Student Assessment (PISA). PISA measures 15-year-old students' abilities to use their reading, mathematics, and science skills to meet real-life challenges (https://www.oecd.org/pisa/).

PISA test questions measure student ability to draw on knowledge and real-world problem-solving skills and, therefore, researchers have concluded that PISA is an important indicator of whether school systems are effectively preparing their students for success in the global knowledge economy of the twenty-first century. The "OECD conducts research on the 65 countries that make up 90 percent of the world's economies. The OECD Directorate for Education has found that student achievement in math and science are a sound indicator for future economic health. In other words, nations or cities with good schools can expect a healthy economy, whereas a nation or city with suffering schools can expect negative consequences to its economy" (Asia Society, n.d., para. 6).

PISA data, collected every 3 years, are often used for benchmarking aimed at driving reform and school turnaround efforts. Knowledge about a nation's placement on this assessment typically affects STEM education policy and provides examples of exemplary educational models. For example, investigating programming in the top five countries (Estonia, Canada, Finland, Ireland, and Korea, in their respective order of accomplishment) reveals common patterns among the top-performing systems and undoubtedly yields replicable implementation models that countries striving to improve could adopt. The most recent PISA results (2019) are depicted in Fig. 4.1.

Although the OECD member countries and associates postponed the PISA 2021 assessment to 2022 and the PISA 2024 assessment to 2025 due to post-COVID difficulties, their 2022 focus will remain on mathematics, with an additional test of creative thinking. "PISA 2025 will focus on science, and include a new assessment of foreign languages. It will also include the innovative domain of Learning in the Digital World which aims to measure students' ability to engage in self-regulated learning while using digital tools" (OECD, n.d.).

Table I.1 [1/2] **Snapshot of performance in reading, mathematics and science**

Countries/economies with a mean performance/share of **top performers above** the OECD average
Countries/economies with a share of **low achievers below** the OECD average
Countries/economies with a mean performance/share of top performers/share of low achievers **not significantly different** from the OECD average
Countries/economies with a mean performance/share of **top performers below** the OECD average
Countries/economies with a share of **low achievers above** the OECD average

	Mean score in PISA 2018			Long-term trend: Average rate of change in performance, per three-year-period			Short-term change in performance (PISA 2015 to PISA 2018)			Top-performing and low-achieving students	
	Reading	Mathematics	Science	Reading	Mathematics	Science	Reading	Mathematics	Science	Share of top performers in at least one subject (Level 5 or 6)	Share of low achievers in all three subjects (below Level 2)
	Mean	Mean	Mean	Score dif.	Score dif.	Score dif.	Score dif.	Score dif.	Score dif.	%	%
OECD: **OECD average**	487	489	489	0	-1	-2	-3	2	-2	15.7	13.4
Estonia	523	523	530	**6**	**2**	0	4	4	-4	22.5	4.2
Canada	520	512	518	-2	**-4**	**-3**	-7	-4	**-10**	24.1	6.4
Finland	520	507	522	**-5**	**-9**	**-11**	-6	-4	**-9**	21.0	7.0
Ireland	518	500	496	0	0	**-3**	-3	-4	-6	15.4	7.5
Korea	514	526	519	**-3**	**-4**	**-3**	-3	2	3	26.6	7.5
Poland	512	516	511	**5**	**5**	2	6	**11**	**10**	21.2	6.7
Sweden	506	502	499	**-3**	-2	-1	6	8	6	19.4	10.5
New Zealand	506	494	508	**-4**	**-7**	**-6**	-4	-1	-5	20.2	10.9
United States	505	478	502	0	-1	2	8	9	6	17.1	12.6
United Kingdom	504	502	505	2	1	-2	6	**9**	-5	19.4	9.0
Japan	504	527	529	1	0	-1	**-12**	-5	**-9**	23.3	6.4
Australia	503	491	503	**-4**	**-7**	**-7**	0	-3	**-7**	18.9	11.2
Denmark	501	509	493	1	-1	0	1	-2	**-9**	15.8	8.1
Norway	499	501	490	1	2	1	**-14**	-1	**-8**	17.8	11.3
Germany	498	500	503	**3**	0	**-4**	-11	-6	-6	19.1	12.8
Slovenia	495	509	507	2	2	**-2**	**-10**	-1	**-6**	17.3	8.0
Belgium	493	508	499	-2	**-4**	**-3**	-6	1	-3	19.4	12.5
France	493	495	493	0	**-3**	-1	-7	2	-2	15.9	12.5
Portugal	492	492	492	**4**	**6**	**4**	-6	1	**-9**	15.2	12.6
Czech Republic	490	499	497	0	**-4**	**-4**	3	7	4	16.6	10.5
Netherlands	485	519	503	**-4**	**-4**	**-6**	**-18**	7	-5	21.8	10.8
Austria	484	499	490	-1	-2	**-6**	0	2	-5	15.7	13.5
Switzerland	484	515	495	-1	**-2**	**-4**	-8	-6	**-10**	19.8	10.7
Latvia	479	496	487	2	2	-1	**-9**	**14**	-3	11.3	9.2
Italy	476	487	468	0	**5**	-2	-8	-3	**-13**	12.1	13.8
Hungary	476	481	481	-1	**-3**	**-7**	6	4	4	11.3	15.5
Lithuania	476	481	482	2	-1	**-3**	3	3	7	11.1	13.9
Iceland	474	495	475	**-4**	**-5**	**-5**	-8	**7**	2	13.5	13.7
Israel	470	463	462	**6**	**6**	3	-9	-7	-4	15.2	22.1
Luxembourg	470	483	477	-1	-2	-2	**-11**	-2	**-6**	14.4	17.4
Turkey	466	454	468	2	**4**	**6**	**37**	**33**	**43**	6.6	17.1
Slovak Republic	458	486	464	**-3**	**-4**	**-8**	5	**11**	3	12.8	16.9
Greece	457	451	452	-2	0	**-6**	-10	-2	-3	6.2	19.9
Chile	452	417	444	**7**	1	1	-6	-5	-3	3.5	23.5
Mexico	420	409	419	2	**3**	2	-3	1	3	1.1	35.0
Colombia	412	391	413	**7**	**5**	**6**	**-13**	1	-2	1.5	39.9
Spain	m	481	483	m	0	-1	m	-4	**-10**	m	m

Notes: Values that are statistically significant are marked in bold (see Annex A3).
Long-term trends are reported for the longest available period since PISA 2000 for reading, PISA 2003 for mathematics and PISA 2006 for science.
Results based on reading performance are reported as missing for Spain (see Annex A9). The OECD average does not include Spain in these cases.
Countries and economies are ranked in descending order of the mean reading score in PISA 2018.
Source: OECD, PISA 2018 Database, Tables I.B1.10, I.B1.11, I.B1.12, I.B1.26 and I.B1.27.
StatLink https://doi.org/10.1787/888934028140

Fig. 4.1 Short-term and long-term trends for each participating PISA country

Government efforts worldwide develop policy-level documents guided by PISA data, as well as data associated with the Trends in International Mathematics and Science Study (TIMMS) gathered by the U.S. National Center for Educational Research, and other country-specific data gathered nationally, to govern their unique school STEM education initiatives. Countries often create policy documents aimed at addressing the ‘STEM crisis’ with regard to unmet labor market demands for STEM skills and the need to remain competitive in the global economy. Freeman et al. (2019) conducted country comparisons and cited several policy reports aimed at the development of a national STEM workforce, such as Australia’s 2015 *National STEM School Education Strategy* and 2018 plan *Australia 2030: Prosperity Through Innovation*; New Zealand’s *National Statement on Science Investment 2015–2025*; the UK’s *Science & Innovation Investment Framework 2004–2014* and 2017 paper, *Industrial Strategy: Building a Britain for the Future;* and, in the United States, the *Rising Above the Gathering Storm* (2007) and *Revisiting the STEM Workforce* (2015) reports.

Their study also revealed that many countries in Western Europe, such as Germany, France, Ireland, the Netherlands, and Spain, have adopted science policies that typically address K–12 school-based science and mathematics teaching, while countries in East and Southeast Asia that have high performing educational systems tend to focus on national policies and plans emphasizing university science and technology programming, industry-driven research and development, and innovation. In addition, they found that emerging economies and education systems, including Brazil, Argentina, and arguably South Africa, have established national policies focused on quality education and emerging industry development. For example, Brazil’s *Education Development Plan 2011–2020* emphasizes school education, teaching quality and teacher career pathways; and Argentina’s *National Plan of Science, Technology, and Innovation: Argentina Innovadora 2020* prioritizes research and innovation, general scientific capacity, and development of biotechnology and health.

Economic development, including the ability to invent and develop new products, drives the policies of many countries. For example, South Africa’s *National Development Plan 2030 of the National Planning Commission* aims to “redress injustices of the past, facilitate economic growth, and improve education, health, and social protection” (p. 6). Additionally, the government of the UAE has promoted STEM fields through its *Vision 2021, Vision 2030, the fourth industrial revolution, and artificial intelligence strategy* (Al Murshidi, 2019, pp. 327–328). These examples clearly demonstrate the diverse STEM policy objectives that generally reflect national cultural, social, and economic/workforce contexts, as well as the need to build strong foundations for STEM literacy and increase diversity, equity, and inclusion in STEM.

With the goal of bringing all countries together, the United Nations’ 2030 Agenda for Sustainable Development established 17 Sustainable Development Goals (SDGs) aimed at tackling global issues, including those related to STEM education (see Chap. 10 for more information). UNESCO’s International Bureau of Education subsequently developed a resource to identify and describe the contributory elements of STEM competencies associated with the four core STEM subjects, along with potential approaches to teaching in a competency-based manner in order to integrate the four STEM disciplines and create a connected field of study (UNESCO International Bureau of Education, 2019). They found that education, and particularly STEM education, plays a critical role in achieving the internationally-agreed upon outcomes associated with the SDGs, since STEM education aspires to elaborate and provide innovative solutions to solve global issues, in particular those directly related to SDG 2 (Zero Hunger); SDG 3 (Good Health and Well-Being); SDG 6 (Clean Water and Sanitation); SDG 7 (Affordable and Clean Energy); SDG 9 (Industry, Innovation and Infrastructure); SDG 12 (Responsible Consumption and Production); SDG 13 (Climate Action); SDG 14 (Life Below Water); and SDG 15 (Life on Land). Moreover, SDG 8 (Decent Work and Economic Growth) and SDG 11 (Sustainable Cities and Communities) are heavily dependent on progress that can be made within the fields of STEM. In the context of Industry 4.0, the contribution of STEM to achieve the SDGs is crucial (UNDP, 2019).

S.T.E.M Education Versus STEM Education

There are multiple definitions of STEM education. The most simplistic of these is STEM as individual subjects, represented as S.T.E.M. going forward. In this configuration, S.T.E.M. simply refers to the individual disciplines. Another view is that STEM is a meta-discipline. This will be represented as STEM going forward. STEM as a meta-discipline focuses on the interconnected nature of the STEM disciplines versus individual implementation of the four disciplines. STEM as a meta-discipline views STEM as a connected and potentially integrated field of study. Both national and international policymakers have advocated for a STEM agenda that increasingly focuses on the need for STEM concepts in the context of the workplace. As a result, STEM educators need to prepare students to have greater S.T.E.M. literacy and a better understanding of how these STEM disciplines are interconnected and relate to one another.

The central tenet of STEM education is the use of STEM knowledge to solve real-world problems. This can be achieved by adopting the definition that STEM is a meta-discipline unto itself and is delivered in a manner that makes STEM learning more meaningful and contextual. According to Bybee (2013, p. 5), STEM literacy is defined as:

- Knowledge, attitudes, skills [and values] to identify questions and problems in life situations. Explain the natural and designed world, and draw evidence-based conclusions about STEM-related issues;
- Understanding of the characteristic features of STEM disciplines as forms of human knowledge, inquiry, and design;

- Awareness of how STEM disciplines shape our material, intellectual, and cultural environments; and
- Willingness to engage in STEM-related issues with the ideas of science, technology, engineering, and mathematics as a constructive, concerned, and reflective citizen.

It should be noted that the STEM perspective adopted and the operational definition that is used to guide policy and instruction have direct educational consequences. If one is using the perspective of S.T.E.M. as simply four independent disciplines, it is unlikely that an interdisciplinary pedagogical approach would be utilized and would appear as a traditional approach to delivering content to students at the primary, secondary and tertiary levels. The S.T.E.M. approach has been the traditional implementation model in most schools globally until recently.

Advocates for delivering STEM as an interdisciplinary approach believe in removing the disciplinary silos and bringing the disciplines together to form a more applied science or meta-discipline. The alignment of the four STEM areas was first proposed in the 1990s by the National Science Foundation in the United States. As discussed earlier, this approach was proposed to address the demand for STEM skills and competencies that did not result from the traditional approach of S.T.E.M. According to Zilberman and Ice (2021), "Science, Technology, Engineering and Mathematics (STEM) occupations are projected to grow over two times faster than the total for all occupations in the next decade. The U.S. Bureau of Labor Statistics (BLS) 2019–2029 employment projections show that occupations in the STEM field are expected to grow 8.0 percent by 2029, compared with 3.7 percent for all occupations" (p. 1).

In the United States and globally, there have been concerns since the late 1970s and early 1980s about the decline in enrollments and involvement in STEM fields at schools, universities, and colleges (Aina & Akanbi, 2013; Milner et al., 1987; Sithole et al., 2017). This decline in enrollment and motivation to pursue STEM academically has been attributed in part to poor pedagogy, content that was not meaningful, and a lack of applicability to real-world contexts, which resulted in students not relating the knowledge and skills that they learned in school to the real world and their future career choices (UNESCO, 2017).

The framework of STEM presented in the UNESCO report *Exploring STEM Competencies for the twenty-first Century* (UNESCO International Bureau of Education, 2019) was organized around societal needs and how the STEM disciplines work together to fulfill those needs. This approach makes STEM relevant to students, as it provides them with theoretical foundations that enable them to propose timely and innovative solutions to issues and problems confronted by society and the world. Figure 4.2 shows the relationship between the STEM components and depicts how the four STEM components work together to meet the societal needs.

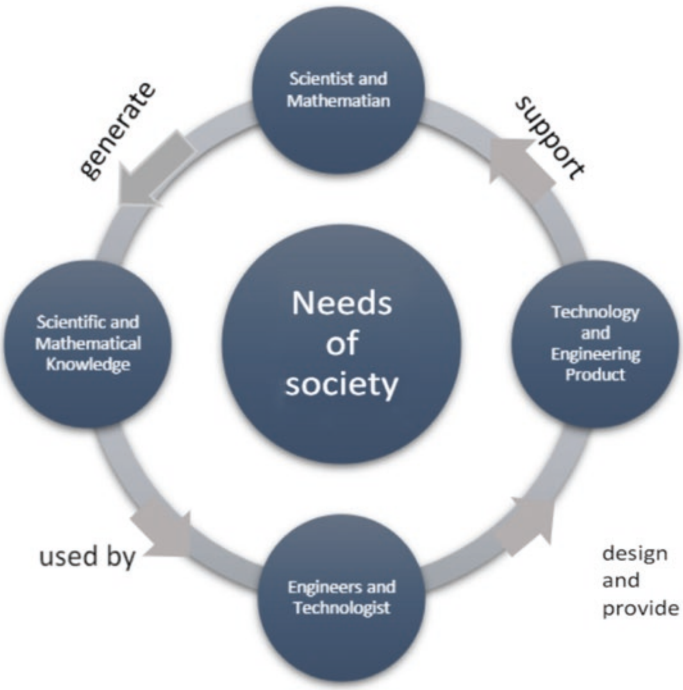

Fig. 4.2 Relationship between the components of STEM (UNESCO International Bureau of Education, 2019, p. 8)

The Evolution of STEM Education

STEM education implementation models continue to evolve. Expanded iterations of the acronym have included additional disciplines as a more holistic approach to education, focusing on individual students' needs and interests. As an example, STEAM education highlights the pedagogical approach that incorporates science, technology, engineering, the Arts and mathematics as access points for student inquiry, creativity, critical thinking and communication. STEAM educators believe that the Arts serve as a mechanism that allows children to incorporate artistic expression to communicate and make better sense of their learning, providing expanded opportunities to reflect, imagine, create, express and represent ideas. They argue that this approach increases student interest and engagement in STEM subjects by integrating creative Arts with various aspects of inquiry-based teaching and learning, including the role of engineering. MacDonald et al. (2019) found that focusing on the spaces between STEM disciplines, the intersections of interdisciplinary study, allows students to discover new insights and gain better understanding of the content areas that they study. According to Holbrook et al. (2020), STEAM education moves beyond disciplines and incorporates a transdisciplinary focus, identifying new knowledge about what is "between, across, and beyond disciplines" (p. 470), further interrelating science education to the relevance and issues of society on local, national, and global scales.

STREAM, an expanded iteration of STEAM education, adds the disciplines of reading and writing. Advocates of STREAM contend that literacy is an essential part of a well-rounded curriculum, requiring critical thinking and creativity (see Chap. 19 for more information on creativity and innovation in science and technology education). Others believe that education should direct itself toward design and design thinking, thereby coining the acronym STEAMD (Henebery, 2020). However, STEAMD has also taken on another definition, extending the approach to focus on the learning of the traditional STEM subjects, include the Arts, but also focusing on the use of drama to scaffold learners' understanding of STEM subjects (McGregor, 2017). This creative use of drama, often implemented in early years/primary education environments, provides opportunities for students to place themselves in scientific roles and encourages engagement in scientific activities (Kennedy & Tunnicliffe, 2022).

Many variations of the STEM acronym exist, such as STEMLE (Science, Technology, Engineering, Mathematics, Law and Economics), and STREM (Science, Technology, Robotics, Engineering and Multimedia), to name a few. STEM curriculum continues to evolve while educators around the world strive to provide application and problem-solving experiences to create more awareness of interdisciplinary opportunities for their students. While some educators advocate for the inclusion of the Arts and Humanities, others argue that STEM curriculum should include the history of science and highlight the contributions of women scientists as well as scientists of color to ensure gender equity and equality. The reality is that STEM education has a place in every aspect of schooling, as it incorporates engineering and technology concepts into the core subjects of math and science throughout the curriculum (see Chaps. 5 and 15 for more information about curriculum design in science and technology education as well as pedagogical content knowledge).

Although some scholars believe that adding an A, R or D is a dilution of STEM's focus and objectives, most agree that the iterations are symbolic reminders that STEM disciplines are enriched by other disciplines and facilitate the learning of all students. The recent COVID-19 pandemic revealed the potential critical thinking and problem-solving capabilities of STEM experts around the world. It also provided primary and secondary students with opportunities to develop and share their STEM solutions globally (Kennedy, 2021). STEM education has become more recognized as a societal solution, expanding across all content areas in a transdisciplinary fashion. Thus, this chapter will generally use the acronym STEM and recognize the contributions of all content areas subsumed within its applications.

Implementing STEM Education

As described earlier, defining STEM is the easy part. Implementing STEM education within the school setting is much more challenging. According to Bybee (2013), part of the problem is the general confusion about what STEM actually looks like in the classroom, since STEM education can take on various forms. It does not always incorporate all four STEM disciplines, and it is not always incorporated into project- or problem-based learning scenarios, also referred to as phenomenon-based learning in many countries (later described in Chaps. 18 and 20). However, nearly all STEM learning experiences have one thing in common—they provide students with opportunities to break down the artificial barriers between disciplines and enable students to better understand the connected nature of knowledge using critical skills, leading to success in the twenty-first century economy through applying the skills and knowledge that they have learned or are in the process of learning (Kennedy & Sundberg, 2020, p. 479). The basic tenet of STEM education aims to create critical thinkers, increase scientific literacy, and develop the next generation of innovators.

The 5E Model of Instruction (see Fig. 4.3) is recognized as one of the best processes by which educators can employ opportunities to personalize STEM learning for students of all ages. The five phases of the 5E Model, Engage, Explore, Explain, Elaborate and Evaluate, have "a 'common sense' value; it presents a natural process of learning" (Bybee, 2015, p. ix).

Based on the cognitive psychology, constructivist theory to learning, the five phases guide the learning process as students *engage* and focus on phenomena to make connections between past and present learning experiences; *explore* their environment using prior knowledge, generating new ideas through experimentation and trial and error to make sense of their surroundings; *explain* their observations

Fig. 4.3 Evidence-based practices: The 5E Model of Instruction. (Graphic used with permission from the San Diego County Office of Education, 2018, https://ngss.sdcoe.net/Evidence-Based-Practices/5E-Model-of-Instruction)

and understandings through their excitement and verbal explanations, and further construct deeper understandings as their peers and the adults around them provide additional information to help them make sense of their learning; and *elaborate* on their understanding through extended/enrichment activities. Students self-*evaluate* their learning and their teachers also evaluate their progress through informal formative assessments and formal summative assessments. See Chap. 14 for more information about educational psychology and its role in science education.

Conclusion

The debate of S.T.E.M versus STEM has generally subsided. Whichever form of STEM education we are referring to, whether it is STEAM, STREAM or others, STEM represents an educational philosophy centered on the integration of subjects (an integrated curriculum), and the ideal of building core competencies in twenty-first century skills (communication, collaboration, creativity, digital literacy, critical thinking and problem-solving) for every learner.

An examination of the research literature supports the interdisciplinary nature of STEM. That said, there is no clear configuration of interdisciplinary STEM derivatives or interdisciplinary variations. Regardless of the specific STEM strategy implemented, STEM education focuses on preparing all students to be problem-solvers and future leaders, workers and citizens who are flexible and can respond to new challenges locally and globally through innovation. STEM education increases student awareness of the technological world in which they live; how science, technology, engineering and mathematics support each other; how to creatively innovate and use new technologies as they become available; and how the technology decisions made directly impact their lives and the lives of others. "Twenty-first century students live in an interconnected, diverse, and rapidly changing world. Emerging economic, digital, cultural, demographic, and environmental forces are shaping young people's lives around the planet and increasing their intercultural encounters on a daily basis. This complex environment presents an opportunity and a challenge. Young people today must not only learn to participate in a more interconnected world but also appreciate and benefit from cultural differences. Developing a global and intercultural outlook is a process—a lifelong process—that education can shape" (OECD, 2018, p. 4).

Summary

This chapter explored STEM as a meta-discipline and discussed the origins and emergence of STEM education. The differences between S.T.E.M and STEM were defined, as were the many variations of the acronym. STEM education policy development continues to evolve in countries around the world, placing STEM literacy as a global priority since governments, business and industry, and educators place competence in STEM disciplines as essential to the global economy, competitiveness in the workforce, and in education. STEM education and research are necessary requirements to a nation's development, productivity, competitiveness, and societal wellbeing.

STEM is an interdisciplinary approach bringing the disciplines together to form a more applied science or meta-discipline, and plays a critical role in achieving the internationally agreed upon outcomes associated with the Sustainable Development Goals (SDGs). STEM education implementation models have evolved to encompass additional disciplines such as the Arts (STEAM), the Arts and drama (STEAMD), reading and writing (STREAM), design and design thinking (STEAMD), law and economics (STEMLE), robotics, engineering, and multimedia (STREM), and continue to evolve while educators around the world strive to provide application and problem-solving experiences to create more awareness of interdisciplinary STEM opportunities for their students.

The 5E Model of Instruction is recognized as one of the best processes by which educators can employ opportunities to personalize STEM learning for students of all ages. Through student-centered approaches such as Project-Based Learning, Problem-Based Learning, and Phenomenon-Based Learning, teachers can facilitate critical thinking through inquiry as they guide students to use their academic knowledge in real-world applications.

Recommended Resources

5 NSF-supported STEM education resources that are perfect for virtual learning https://beta.nsf.gov/science-matters/5-nsf-supported-stem-education-resources-are

21 Amazing STEM resources for teachers https://www.thetechedvocate.org/21-amazing-stem-resources-teachers/

10 great STEM sites for the classroom https://www.educationworld.com/a_lesson/great-stem-web-sites-students-classroom.shtml

References

Aina, J. K., & Akanbi, A. G. (2013). Perceived causes of students' low enrolment in science in secondary schools, Nigeria. *International Journal of Secondary Education, 1*(5), 18–22.

Al Murshidi, G. (2019). STEM education in the United Arab Emirates: Challenges and possibilities. *International Journal of Learning Teaching and Educational Research, 18*(12), 316–332.

Asia Society. (n.d.). *What is PISA and why does it matter? Global Cities Education Network.* https://asiasociety.org/global-cities-education-network/what-pisa-and-why-does-it-matter

Bybee, R. W. (2013). *The case for STEM education: Challenges and opportunities*. NSTA Press.

Bybee, R. W. (2015). *The BSCS 5E instructional model: Creating teachable moments*. NSTA Press. https://static.nsta.org/pdfs/samples/PB356Xweb.pdf

Freeman, B., Marginson, S., & Tytler, R. (2019, August). *An international view of STEM education.* Available at: https://www.researchgate.net/publication/335551705_An_international_view_of_STEM_education

Gonzalez, H. B., & Kuenzi, J. (2012). *Science, technology, engineering, and mathematics (STEM) education: A primer.* Congressional Research Service. http://www.stemedcoalition.org/wp-content/uploads/2010/05/STEM-Education-Primer.pdf

Henebery, B. (2020, December 11). *What makes an award-winning STEM program?* The Educator. https://www.theeducatoronline.com/k12/news/what-makes-an-awardwinning-stem-program/274741

Holbrook, J., Rannikmäe, M., & Soobard, R. (2020). STEAM education: A transdisciplinary teaching and learning approach. In B. Akpan & T. J. Kennedy (Eds.), *Science education in theory and practice: An introductory guide to learning theory* (pp. 465–477). Springer nature. https://doi.org/10.1007/978-3-030-43620-9

Kennedy, T. J. (2021, August 10). Student innovations related to COVID-19: The international engineering design challenge. *American Journal of Biomedical Science & Research. 13*(6), 592–595. https://biomedgrid.com/pdf/AJBSR.MS.ID.001921.pdf

Kennedy, T. J., & Odell, M. R. L. (2014). Engaging students in STEM education. *Science Education International, 25*(3), 246–258. https://eric.ed.gov/?id=EJ1044508

Kennedy, T. J., & Sundberg, C. W. (2020). 21st century skills. In B. Akpan & T. J. Kennedy (Eds.), chapter 32 *Science education in theory and practice: An introductory guide to learning theory* (pp. 479–496). Springer nature. https://doi.org/10.1007/978-3-030-43620-9

Kennedy, T. J., & Tunnicliffe, S. D. (2022) 'Introduction: The role of play and STEM in the early years'. In: *Play and STEM education in the early years: International policies and practices,* Tunnicliffe, S. D. & Kennedy, T. J. (Eds.), Chapter 1, pp. 3–37. Springer nature. https://link.springer.com/chapter/10.1007/978-3-030-99830-1_1

MacDonald, A., Hunter, J., Wise, K., & Fraser, S. (2019, July). STEM and STEAM and the spaces between: An overview of education agendas pertaining to "disciplinarity" across three Australian states. *Journal of Research in STEM Education, 5*(1), 75–92.

Marginson, S., Tytler, R., Freeman, B., & Roberts, K. (2013). *STEM: Country comparisons: International comparisons of science, technology, engineering and mathematics (STEM) education. Final report*. Australian Council of Learned Academies, Melbourne, Vic. https://www.researchgate.net/publication/305063165_STEM_country_comparisons_international_comparisons_of_science_technology_engineering_and_mathematics_STEM_education_Final

McGregor, D. (2017). *Using drama within a STEM context: Developing inquiry skills and appreciating what it is to be a scientist!* RADAR, Institutional repository of Oxford Brookes University. https://radar.brookes.ac.uk/radar/file/821f00c4-14bf-43f2-a4d8-b72f51323bae/1/mcgregor2017STEM.pdf

Milner, N., Ben-Zvi, R., & Hofstein, A. (1987). Variables that affect students' enrolment in science courses. *Research in science and technological education,* ***5***(2), 201.

NGSS Lead States. (2013). *'Appendices'. Next generation science standards: For States, by States, 2*. The National Academies Press.

OECD. (2018). *Preparing our youth for an inclusive and sustainable world.* Organisation for Economic Co-operation and Development. https://www.oecd.org/education/Global-competency-for-an-inclusive-world.pdf

OECD. (2019). *PISA 2018 results: Combined executive summaries*. Organisation for Economic Co-operation and Development. https://www.oecd.org/pisa/Combined_Executive_Summaries_PISA_2018.pdf

OECD. (n.d.). *What is PISA?* Organisation for Economic Co-operation and Development. https://www.oecd.org/pisa/

Sithole, A., Chiyaka, E., McCarthy, P., Mupinga, D., & Bucklein, B. (2017). Student attraction, persistence and retention in STEM programs: Successes and continuing challenges. *Higher Education Studies, 7*(1), 46–59. https://www.researchgate.net/publication/312474142_Student_Attraction_Persistence_and_Retention_in_STEM_Programs_Successes_and_Continuing_Challenges

UNDP. (2019). *Human development report 2019: Beyond income, beyond averages, beyond today: Inequalities in human development in the 21st century*. United Nations Development Programme. https://hdr.undp.org/system/files/documents//hdr2019pdf.pdf

UNESCO. (2017). *Education for sustainable development goals: Learning objectives.* https://unesdoc.unesco.org/ark:/48223/pf0000247444?utm_sq=gj34xbfn94

UNESCO International Bureau of Education. (2019, February). *Exploring STEM competencies for the 21st century, 30*. https://unesdoc.unesco.org/ark:/48223/pf0000368485

Zilberman, A., & Ice, L. (2021, January). *Employment projections for STEM occupations*. U.S. Bureau of Labor Statistics. https://www.bls.gov/opub/btn/volume-10/why-computer-occupations-are-behind-strong-stem-employment-growth.htm

Teresa J. Kennedy is a Professor of International STEM and Bilingual/ELL Education in the College of Education and Psychology at the University of Texas at Tyler. She holds appointments in the School of Education and the College of Engineering. She is a Past President of the International Council of Associations for Science Education, and currently serves on the ICASE Executive Committee, is a member of the UNESCO NGO Liaison Committee, and serves on the NSTA International Advisory Board. Her research interests include international comparative education, gender and equity issues in STEM, and content-based second language teaching and learning focused on STEM disciplines. Dr. Kennedy holds a PhD in Curriculum and Instruction from the University of Idaho.

Michael R. L. Odell is a Professor of STEM Education and holds the Sam and Celia Roosth Chair in the College of Education and Psychology. He holds appointments in the School of Education and the College of Engineering. He is the Co-Founder of the University Academy Laboratory Schools and serves on the School Board. He also provides oversight for the UA Curriculum. He is the Co-Director of the UTeach STEM Teacher Preparation program and the Co-Director of the EdD in School Improvement Program. His research interests are Education Policy, Sustainable Education, PBL, School Improvement, and STEM Education. Dr. Odell holds a PhD in Curriculum and Instruction from Indiana University.