Chapter

Integrating STEM: An Interdisciplinary Approach to PreK-12 Education

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Abstract

STEM education employs an interdisciplinary pedagogical approach that merges the subjects of science, technology, engineering, and mathematics into traditional disciplines covered across all levels within primary and secondary school curricula. STEM topics span the United Nation's Sustainable Development Goals (SDGs) and naturally weave STEM disciplines throughout, focusing on the importance of developing a global STEM-literate workforce capable of responding to the worldwide challenges presented today and into the future. STEM-focused frameworks provide students with the knowledge and skills they need to be successful in the twenty first century and beyond, preparing them for the rapidly changing technological and scientific landscapes. This chapter explores STEM as a meta-discipline, documenting the origins and emergence of STEM education in the United States, provides definitions of STEM literacy and includes primary and secondary implementation models.

Keywords: science, technology, engineering, mathematics, STEM, STEM education, interdisciplinary frameworks, interdisciplinarity, twenty first century skills, primary STEM pedagogy, secondary STEM pedagogy, sustainable development goals (SDGs)

1. Introduction

The origins of STEM Education in the United States can be traced back to the launch of Sputnik by the Soviet Union in 1957. There was concern in the Western World that national security required investing in science and mathematics education to maintain safety and remain competitive economically. Over time, concerns about STEM competitiveness have increasingly focused more heavily on economic competitiveness and technological innovation in a global economy. This trend can be seen in reports such as *A Nation at Risk* [1], which served as a reaction to the U.S. perception that it was losing its competitive edge as new economic powers were rising in Asia and Europe. Additionally, the release of the results of the *Trends in International Mathematics and Science Study* (TIMMS) beginning in 1995 showed that U.S. students were not achieving at high levels when compared to students in other developed nations. These same achievement trends had also been presented in the Program for International Student Assessment (PISA) results since 1997, inspiring the 2007 National Academy of Sciences report *Rising above the gathering storm: Energizing and* *employing America for a brighter economic future* (RAGS) and its sequel, *Rising Above the Gathering Storm Revisited: Approaching Category 5* (RAGSR), in 2010 which once again sounded the alarm concerning U.S. student achievement in relation to other countries internationally [2, 3]. However, compared to earlier alarmist reports, the RAGS report provided suggestions for educational interventions that were practical at scale. These recommendations, referred to as *actions,* included the following:

1.1 Action A-1: annually recruit 10,000 science and mathematics teachers by awarding 4-year scholarships and thereby educating 10 million minds

The U.S. federal government and individual state governments have invested heavily in STEM education since the 1990s. Several initiatives, such as the National Science Foundation Robert Noyce Teacher Scholarship Program initiated in 2002, provided college students with significant scholarships if they sought a teaching credential and joined the K-12 teaching force. Private initiatives such as 100Kin10, referring to training 100,000 new Math and Science Teachers in 10 years, from 2011 to 2021, provided funding and support through partnerships to prepare new science and mathematics teachers. The U.S. Department of Education and almost every U.S. state also provided student loan relief for college graduates who chose to teach STEM disciplines in "high needs schools" (public schools located in areas where 30% or more of the student population comes from families with incomes below the poverty line). Additionally, large university networks, such as the UTeach Program, created teacher pathways that allow college students to earn a 4-year degree and a teaching certificate concurrently, supporting the preparation of preservice science teachers [4]. UTeach is currently implemented in 55 universities across the United States and has prepared over 8,300 new STEM teachers since 1997 [5]. While there is still a critical shortage of STEM K-12 teachers in the U.S., progress is being made.

1.2 Action A-2: strengthen the skills of 250,000 teachers through training and education programs at summer institutes, in master's programs, and in advanced placement (AP) and international baccalaureate (IB) training programs

Since the 1960s, there has been significant investment in teacher professional learning, with a significant focus on mathematics beginning in the 1990s. The U.S. Department of Education provides funds to all states for teacher professional development to support effective instruction under a section of the U.S. education law within the *Every Student Succeeds Act* (ESSA, Title II-A). In addition, teachers are required to engage in professional learning as a requirement of recertification. Many states also reimburse teachers who enroll and complete AP and IB training programs to make advanced coursework available to their students since high school teachers who seek to teach dual credit courses must earn a master's degree with 18 credit hours in the STEM discipline to qualify as a university instructor.

In the 2000s, the emergence of dual credit/dual enrollment opportunities allowed secondary students to enroll in college level courses during their high school years. According to the Texas Higher Education Coordinating Board [6], roughly 12,000 high school students enrolled in dual credit courses in the state of Texas alone in 1999. In 2020, that number exceeded 370,000 high school students, and during the 2021–2022 academic year, over 300,000 Texas students enrolled in AP coursework. Additionally, THECB documented 181 International Baccalaureate (IB) Schools in

Texas. This trend is not unique to Texas. Since the 1990s, there has been an increase in access to advanced coursework in the U.S., although access is not evenly distributed.

1.3 Action A-3: enlarge the pipeline of students who are prepared to enter college and graduate with a degree in science, engineering, or mathematics by increasing the number of students who pass AP and IB science and mathematics courses

Two recommendations specifically described how to engage students in STEM in a manner that would prepare them to enter college and graduate with a STEM degree. The first of these called for states to develop *Statewide specialty high schools*, based on the rationale that specialty secondary education could foster leaders in science, technology, and mathematics since they immerse students in high-quality STEM education, serve as a mechanism to test teaching materials, and also provide a training ground for teachers. School models that were developed to address Action A-3 included Residential State STEM Academies, Schools within a School, STEM Magnet Schools, Early College High Schools, and University Affiliated Laboratory Schools. **Table 1** provides a description of each model as well as an example school in the state of Texas, USA.

The five models highlighted prepare students to transition to a STEM degree program of their choice upon completion. These models showcased K-12 or secondary schools collaboratively designed through the guidance of their partnering institution of higher education or educational organization.

K-12 laboratory schools have a long history in the United States as well as worldwide. Just as their educational policies and practices can differ, so do their admission and enrollment criteria. While some schools follow requirements or restrictions that determine whether students are eligible to attend, others are "open enrollment" schools, allowing students to enroll on a first-come, first-serve bases without strict admission requirements, regardless of the student's location or district. Typically, a lottery system, a random selection process that determines which students can enroll, is implemented when more students apply than space allows. For example, the University of Texas at Tyler University Academy is an open enrollment public school focused on K-12 pathways leading to engineering and/or biomedical sciences. Similar to the Early College High School (ECHS) model, students can earn college credits while enrolled in high school, but also have the advantage of being located on a university campus which allows for participation in unique research opportunities. The University Academy also serves as a research and clinical teaching platform to provide authentic STEM teaching and learning experiences.

STEM Pathway programs provide innovative school improvement science models [7]. Research has shown that students, who attend schools focusing on STEM or pursue a STEM Pathway while enrolled in a traditional school, have a higher likelihood to pursue a STEM degree in college [8]. For context, the most recent graduation class of the University of Texas at Tyler University Academy, 100% of graduates are pursuing postsecondary education opportunities with 87% of graduates enrolling in a STEM degree program. Although STEM schools can have a positive impact on college enrollment in STEM fields, it should be noted that schools are not the only factor influencing students' decisions. Personal interests, family support, socioeconomic factors, and individual motivations also play a role in determining whether students pursue STEM degrees in college.

The RAGS report recommended that middle and high school students engage in inquiry-based learning including laboratory and real-world experiences and research.

K-12 STEM School Models in the United States	
K-12 School Model	**Description and Example School**
Residential State STEM Academies	K-12 schools seeking to bring the best and brightest students from across a state to study STEM in a residential boarding school setting. Students enroll in college degree programs and receive additional supports and experiences as they pursue their selected STEM pathway. Prominent RSSA program in Texas: The Texas Academy of Mathematics and Science at the University of North Texas (Denton, Texas). https://tams.unt.edu/
Schools within a School	K-12 schools offering multiple specialty programs in diverse areas while sharing common courses and electives that are operated under the larger umbrella of the school. Students are provided with diverse opportunities that cater to their differing learning needs and interests within a single facility. Prominent SWS program in Texas: School of Science and Engineering (SEM) at Townview Magnet Center (Dallas, Texas). https://www.dallasisd.org/semagnet
STEM Magnet Schools	Secondary schools operating within an existing school district as schools of choice, focusing on a specific area such as STEM, Fine Arts, or Leadership, or a combination of areas. Additionally, all subjects are taught through the lens of the school focus. Prominent SMS program in Texas: Liberal Arts and Science Academy (Austin, Texas). https://www.austinisd.org/schools/lasa
Early College High Schools	Secondary schools partnering with an institution of higher education to enable students to earn college credits concurrently while completing their high school course requirements. In some cases, students earn an associate degree from a community college or complete up to 2 years toward a STEM degree from the partner university. Prominent ECHS program in Texas: Houston Community College Associate of Science in Engineering Science (ASES) Program (Houston, Texas). https://www.hccs.edu/programs/areas-of-study/science-technology-engineering--math/engineering/ut-tyler-engineering/course-sequence-chart/
University Affiliated Laboratory Schools	K-12 schools partnering with an institution of higher education to provide a unique learning environment for students within a structured environment for experimenting with curriculum designs, educational technologies, and new teaching methods. Laboratory Schools have the added mission of preparing new teachers. While there are currently over 100 U.S. lab schools, only a few focus exclusively on STEM. Prominent UALS in Texas: University of Texas at Tyler University Academy (Campuses in Tyler, Longview and Palestine, Texas). https://www.uttua.org/

Table 1.
K-12 U.S. school models developed to address RAGS report action A-3.

However, many programs recognize the importance of including younger students, as can be seen in **Figure 1**. Research has shown that early childhood settings (including pre-primary school experiences) support STEM learning since "young children are capable of engaging in, at developmentally appropriate levels, the scientific practices that high school students carry out" ([10], p. 2; [11], p. 16). This makes sense since STEM capabilities begin in the initial early years with the development of manipulative skills, learning about safety and following safety rules and instructions, recognizing a problem, planning and identifying the necessary items to solve the problem, realizing

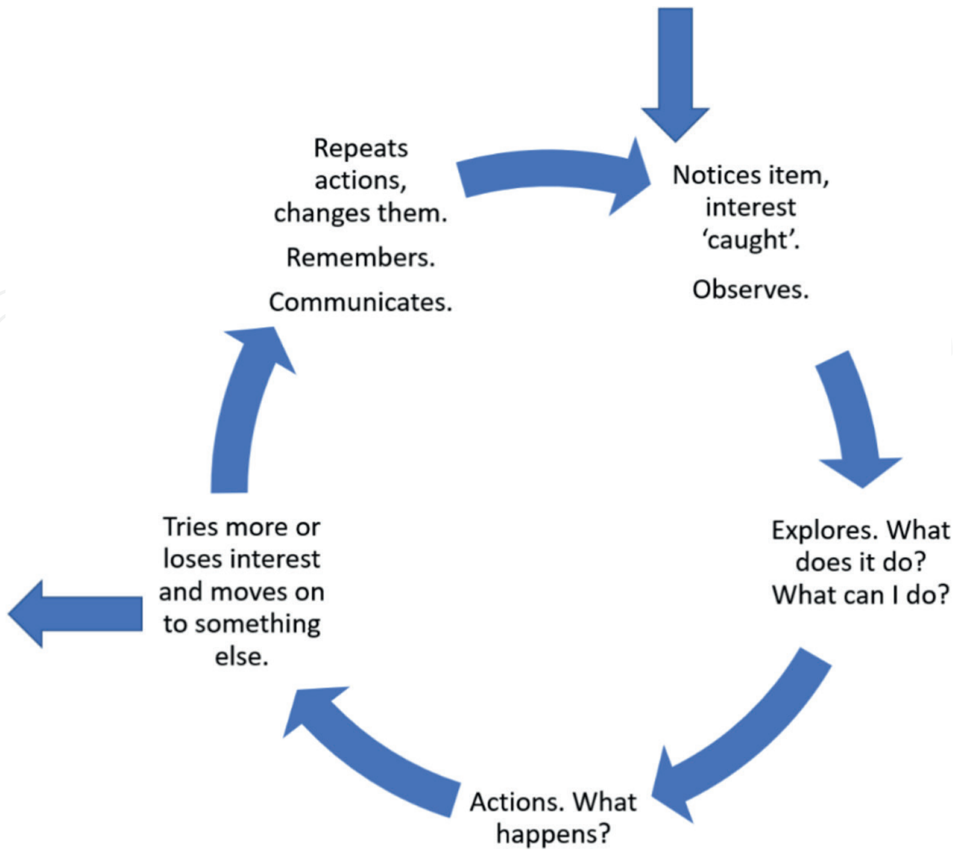

Figure 1.
The STEM play cycle [9].

a design, evaluating outcomes, and changing paths; a process that celebrates successful discovery and allows for redirection to the next problem encountered [12, 13].

Young children constantly attempt to solve problems they encounter in their environment, regardless of whether they are engaged in their own discoveries, involved in formal education activities (occurring during academic schooling), or informal education activities (occurring outside of the classroom; at a playground, camp, museum, etc.). **Figure 1** shows the STEM Play Cycle, promoting creativity as children observe, question, explore, investigate, and construct meaning through problem-solving and applying previous experiences. The cycle is continuous until the child moves on to a different variation of inquiry or losses interest and moves on to something completely new.

According to the National Science Teaching Association ([14], p. 1), "learning science and engineering practices in the early years can foster children's curiosity and enjoyment in exploring the world around them and lay the foundation for a progression of science learning in K-12 settings and throughout their entire lives." STEM education naturally brings the concepts of investigation and design together through all four disciplines it subsumes since scientific inquiry involves the formulation of a question that could be answered through *investigation*, and engineering design involves the formulation of a problem that could be solved through *design* ([15], p. 247).

2. K-12 STEM education and twenty first century skills

The National Education Association of the United States developed the *Framework for 21st Century Learning* in 2002 through a collaboration of educators, education experts, and business leaders, with the goal of defining the skill set needed for success in work, life, and citizenship [16]. The framework consisted of 18 skills, which were further refined into four learning and innovation skills in 2012. Referred to as the Four C's, these skills include critical thinking, communication, collaboration, and creativity [17].

The Four C's are highlighted in many twenty first century skills (21CS) policy documents from around the globe, often including social and emotional intelligence, technological literacy, and problem-solving skills [18]. Education systems, both formal and informal, play a critical role in fostering development of 21CS. Joynes et al. [19] cited a broad range of literature discussing 21CSs, concluding that "there is evidence of general agreement across commentators on the need for new forms of learning to tackle global challenges" (p. 40). The challenge then becomes combining *hard skills* (scientific content) with *soft skills* (effective verbal written communication, career readiness, emotional I.Q., collaboration, creativity, work ethic) to build greater connections between the two. Within the context of STEM, essential skills include rigorous core content (biology, chemistry, Earth sciences, engineering, mathematics, physics, and technology) combined with critical thinking skills [20]. Curriculum that focuses on cognition of core constructs within the framework of 21CS provides opportunities for students to apply critical thinking and problem-solving in perspective with real-world scenarios.

Specific 21CS connections with STEM education include:

- Critical Thinking and Decision Making: Students identify and analyze complex problems, break them down into manageable parts, and develop innovative solutions through problem-solving.

- Collaboration and Communication: Through different variations of PBL, students work in teams to tackle real-world challenges. This collaborative approach facilitates the development of strong communication skills, helps students learn to work effectively with others, and promotes appreciation of diverse perspectives.

- Creativity and Innovation: STEM fields naturally foster a culture of creativity as students design new technologies, conduct experiments, or invent novel solutions.

3. STEM education and connections to UNESCO's education goals

To this point, this chapter has provided examples from the United States. As presented, the U.S. has responded to several critical reports about the status of STEM Education. There is another series of reports from the Intergovernmental Panel on Climate Change (IPCC) that has many in the U.S. thinking more globally. These reports have sounded the alarm about climate change and its impact on all facets of life. Beyond testing comparison such as PISA, what is the role of STEM Education now that there is a crisis that impacts everyone regardless of nationality? The United Nations Educational, Scientific and Cultural Organization (UNESCO) aims to address this crisis through STEM education, which is closely related to the education goals set by UNESCO, as outlined in its Education 2030 agenda. The goals emphasize the importance of quality education for all, lifelong learning opportunities, and the promotion of sustainable development. STEM education aligns with several key aspects of UNESCO's education goals.

The Sustainable Development Goals (SDGs), established by the United Nations in 2015 in support of the 2030 Agenda for Sustainable Development, are a set of independent yet interconnected goals created with the twenty first century skills framework in mind. **Figure 2** lists the 17 SDGs that weave STEM disciplines throughout with the collective goal of ending poverty, protecting the health of our planet, and providing equitable educational opportunities to ensure that, by 2030, all members of civil society can engage in prosperous and fulfilling lives.

Quality Education (SDG 4) is dedicated to ensuring inclusive and equitable quality education for everyone on a global scale. STEM education plays a significant role in achieving this goal by providing students with the knowledge and skills needed for success in our changing world. SDG 4 specifically employs 21CS through the development of critical thinking, problem-solving, and analytical skills, which are essential for lifelong learning and personal development. Additionally, one of UNESCO's key priorities is the promotion of gender equality in education. STEM fields have historically been male-dominated [21], and UNESCO aims to address this gender gap by empowering girls and women to pursue STEM education and careers (SDG 5) as well as competitively enter all areas of the global workforce. SDG 4 also emphasizes the importance of lifelong learning, from informal and formal education opportunities to continuous skill development and knowledge acquisition throughout one's lifetime. STEM education encourages a mindset of curiosity, questioning, inquiry, and adaptability. It promotes lifelong learning and active engagement in civil society.

In addition to education, the SDGs cover a wide range of global challenges, including poverty, inequality, climate change, life on land and below water, as well as environmental sustainability in all areas. STEM education plays a crucial role in addressing every one of these challenges. For example, STEM subjects provide the foundation for advancing healthcare and technology to improve people's lives (SDG 9), they address environmental issues and the development of clean energy solutions (SDG 7) and smart and sustainable urban solutions (SDG 11). STEM enables us to better understand and protect our ocean which regulates our climate, generates

Figure 2.
Sustainable development goals. (Graphic used with permission by the division of science policy and capacity building, UNESCO natural sciences sector: https://en.unesco.org/sustainabledevelopmentgoals).

over half of the world's oxygen, and absorbs 50 times more carbon dioxide than our atmosphere. STEM education is vital for understanding and conserving marine and terrestrial ecosystems (SDGs 14 and 15), and it prepares students to better understand how to contribute to climate mitigation and adaptation efforts. Addressing climate change (SDG 13) requires a strong understanding of science and technology. STEM education prepares students to engage in climate-related research and the development of green technologies, as well as equips students with the knowledge and skills needed for environmental research, conservation, and sustainable resource management. From SDG 1 (ending poverty) to promoting interdisciplinary collaboration and partnerships (SDG 17), STEM education advances essential 21CS that cross all areas of civil society and equip students with the skills they need to drive future innovation in our rapidly evolving world, preparing the next generation to address global challenges and actively contribute to a more equitable and sustainable future.

4. Inquiry-based STEM teaching and learning

Over the past 20 years, STEM has been increasingly viewed as an integrated meta-discipline due to the natural relationships among science, technology, engineering, and mathematics. This shift removes the traditional barriers between individual STEM content areas and focuses on innovation and the applied process of designing solutions to complex contextual problems, challenging students to innovate and invent, while also promoting problem-solving and critical thinking skills that can be applied to their academic as well as everyday lives ([22], pp. 37–38). Although, it is still common for STEM disciplines to be viewed and taught as distinct content areas, most of them acknowledge that they are both interconnected and interdependent. Schools that focus on STEM are adopting and implementing inquiry-based interdisciplinary approaches to engage students in authentic STEM learning that provides relevance in the real world.

As outlined in **Table 1**, specific STEM school models or approaches can vary by location, educational system, and student interest. Some STEM schools may focus on a particular STEM discipline, such as computer science or environmental science, while others take a more holistic approach to STEM education. However, the end goal of each of these school models is to prepare students for careers in STEM fields as well as create STEM-literate citizens by providing a strong foundation in science, technology, engineering, and mathematics.

According to Bybee [23], STEM education can take on various forms depending on the way STEM subjects are presented in the classroom. However, most STEM learning experiences do have one thing in common—they seek to provide students with opportunities to remove the artificial boundaries between STEM disciplines so that students can 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 ([18], p. 479).

STEM specialty school models tend to engage students in inquiry-based learning such as the 5E Model of instruction. The five phases of the 5E Model are Engage, Explore, Explain, Elaborate, and Evaluate which provides "a 'common sense' value; it presents a natural process of learning" ([24], p. ix). **Figure 3** shows this process.

STEM specialty school models tend to implement different variations of project-based learning (PBL), problem-based learning (PrBL), and phenomena-based learning (PhBL) through implementation of the 5E Model. Summaries of each follow.

Figure 3.
Evidence-based practices: The 5E model of instruction [25]. (Graphic used with permission from the San Diego County Office of Education, 2018. https://ngss.Sdcoe.Net/evidence-based-practices/5E-model-of-instruction.

Project-based learning (PBL) is a student-centered instructional approach that focuses on students actively engaging in real-world, meaningful projects to gain knowledge and develop skills. PBL emphasizes hands-on, experiential learning, rather than passive learning through lectures and memorization. While PBL generally deemphasizes traditional lectures in favor of more active and collaborative learning, it does not necessarily exclude lectures altogether. Lectures, when included, are integrated into the overall PBL framework in a targeted and strategic manner. In this sense, lectures do not serve as the primary mode of content delivery and instead serve specific purposes such as providing an introduction to concepts prior to the beginning of the project; skill development and techniques needed to successfully complete the project; guidance and clarification on instructions and common challenges that arise during the project; reflection and debriefing after the completion of project phases; and when experts deliver a guest lecture to provide real-world perspectives or inspire students. In a PBL setting, students typically work on a project over an extended period, during which they explore and investigate a specific topic or problem resulting in a product that is presented publicly.

Key characteristics of project-based learning include:

1. Real-World Relevance: Students are presented with a problem or challenge and develop projects to address a real-world problem or question. This is designed to make the learning experience more meaningful and applicable to students' lives.

2. Inquiry: Students are encouraged to ask questions, conduct research, and explore topics collaboratively. This is designed to promote deeper learning and critical thinking.

3. Collaboration: PBL typically involves students working in collaborative groups. This approach mirrors real-life work environments where teamwork is required and provides the students with the opportunity to share ideas, engage in problem-solving, and learn from each other.

4. Ownership: PBL facilitates students taking ownership of their own learning by providing a level of voice in choice in the learning process. Students have a say in the direction of their project. Students utilize soft skills to collaborate, manage time, and meet their project goals.

5. Interdisciplinary: In many cases, PBL requires an interdisciplinary approach requiring students to connect and apply knowledge and skills from multiple disciplines.

6. Assessment: Assessment in PBL focuses on the quality of the final project. Students are typically provided with requirements and rubrics as a standard or aspirations that the final product must meet.

7. Reflection: In PBL, students are encouraged to reflect on their learning. Teachers provide students with checkpoints along the way so that students can gauge their progress. In some cases, traditional assessments are included so that students are prepared for high stakes tests.

8. Public Presentation: Students present their final product to their peers, teachers, and experts when practical, to help them develop critical presentation skills and enhance communication skills.

Project-based learning is seen as an effective way to foster critical thinking, creativity, problem-solving, and a deeper learning of subject matter. It also prepares students for the challenges and demands of the real world by giving them opportunities to apply their knowledge in authentic contexts. Furthermore, the implementation of PBL has been shown to be an effective STEM school reform model [26] that can be applied in various educational settings, from K-12 classrooms to higher education and professional development programs. While it is an engaging instructional approach, it is quite different from traditional teaching methods and requires teacher training to ensure understanding of PBL principles, how to facilitate student inquiry and manage classroom dynamics involving group work and collaboration, and assessment of the learning process, collaboration, and critical thinking,

4.1 Problem-based learning

Problem-based learning (PrBL) is similar to Project-based learning; however, it begins with a real-world complex problem or challenge. In PrBL, the learning process begins with the presentation of a problem or a challenge, and students are tasked with exploring, analyzing, and solving that problem over a specified time period. This approach has often been utilized in medical schools, but is also implemented in K-12 settings, especially in mathematics classrooms.

Unique features of PrBL in contrast to PBL include:

1. Teacher as Facilitator: Instead of traditional lecturing, instructors using PrBL serve as facilitators. They provide support and resources to help students navigate the problem-solving process but do not dictate solutions.

2. Assessment in PBL is often based on the quality of the solutions proposed. Assessment focuses on depth of understanding demonstrated, and the process of learning. Student products may involve presentations, written reports, discussions, or other forms of evaluation.

3. Reflective thinking is an essential component of PBL. Students are encouraged to assess their own learning process, identify gaps in their knowledge, and set goals for further learning.

Problem-based learning targets students developing a deep understanding of the content covered, utilize critical thinking skills and self-directed learning abilities, and focus on the application of knowledge in real-world contexts. It encourages students to become self-learners, capable of addressing the complex problems they may face in future careers.

4.2 Phenomena-based learning (PhBL)

Phenomena-based learning (PhBL) is a variant of PBL that revolves around students exploring complex, real-world phenomena that are of interest to them [27]. This educational movement was initiated by Finland's educational system in 2016 striving to expand traditional project-based learning (PBL) and problem-based learning (PrBL) approaches into learning experiences that immerse students deeper into contextual situations aligned with real-life issues while also applying knowledge and skills from multiple disciplines. As with PBL and PrBL, students are encouraged to share their innovative solutions widely.

The unique aspects of PhBL include:

- Phenomena-based learning starts with the identification of a central phenomenon, often chosen based on its relevance to students' lives or the curriculum. This phenomenon serves as the anchor for student learning.

- Phenomena-based learning (PhBL) emphasizes the application of knowledge and skills in authentic contexts. Students learn by addressing real-world problems related to the chosen phenomenon, making the learning experience more meaningful.

Phenomena-based learning (PhBL) projects often begin when students are personally impacted by a specific phenomenon. For example, the COVID-19 Engineering Design Challenge, spanning 2020–2023, engaged over 1000 students from 14 countries to design solutions to challenges and worldwide problems related to the pandemic [28]. Students were encouraged to identify areas of need, brainstorm and design solutions, and communicate their ideas to their classmates, families, and community members via online environments or following physical distancing guidelines established by their teachers and/or schools.

PBL, PrBL, and PhBL are effective methods for promoting deeper learning. The success of these approaches depends on the quality of instruction, the relevance of the chosen problems or phenomena, and the support provided to students as they learn. These methodologies are especially suited to STEM.

4.3 PBL/PrBL/PhBL products

STEM-focused schools engage in a wide range of real-world projects that are designed to apply and deepen student understanding of STEM concepts and skills. These inquiry-based projects emphasize hands-on learning, problem-solving, and collaboration. Specific projects can vary depending on the curriculum, resources, and student interest.

Samples include:

- Engineering Design Projects
- Scientific Investigations
- Computer Coding
- Software Development
- Environmental Studies
- Computer Modeling (Mathematics)
- Robotics Challenges
- Aerospace Design
- Biomedical and Health Science Projects
- Innovation Challenges
- Local Community Service Project
- Competitions

Projects are designed to help students learn STEM content, but they also serve the function of helping students develop critical thinking, problem-solving, teamwork, and communication skills. Where applicable, projects can provide opportunities for students to collaborate with industry professionals, mentors, and experts in the field, which can often be a barrier for many schools due to location and lack of opportunities to interact with professionals, especially in rural areas. However, the pandemic illustrated the value of web-based conferencing to bring experts into the classroom remotely. Projects can span across schools and grade levels and include virtual participation as well.

4.4 The role of the teacher in PBL, PrBL, and PhBL

In PBL, PrBL, and PhBL, teachers play a crucial role in guiding and facilitating the learning process. While these pedagogical frameworks shift some of the responsibility for learning to students, teachers remain essential to create a supportive and structured environment.

Key roles include:

- Design and planning. Teachers select or approve appropriate projects, problems, or phenomena, align them with curriculum standards, establish learning goals, and define the scope of the project.

- Introduce the projects to students. Teachers frame the problem or challenge, explain its relevance by making connections between the project and real-world applications, and assist students to understand the project's purpose, objectives, and overall expectations. They may invite guest speakers or arrange field trips to enhance this connection.

- Model specific skills or processes relevant to the project. Teachers demonstrate how to approach specific tasks or challenges and foster a growth mindset by encouraging students to embrace challenges, persevere through difficulties, and view failures as opportunities for learning and improvement.

- Create a collaborative learning environment. Teachers facilitate group dynamics by building student teamwork skills (assisting students to navigate conflicts or challenges within their teams) and build a positive and supportive classroom culture (celebrate students' success and achievements).

- Monitor students' progress throughout the project. Teachers schedule check-ins and conferences to discuss work progress and ensure students stay on track and meet deadlines.

- Scaffold instruction to support students' learning. Teachers offer advice and guidance, provide relevant resources and supports to help students successfully navigate projects, and suggest alternate approaches when needed.

- Facilitate the inquiry process. Teachers encourage students to ask questions, explore topics, seek additional sources of information, and conduct research.

- Design assessment rubrics and criteria for evaluating student work. Teachers provide formative (ongoing) feedback to help students improve their project work and meet learning objectives and promote metacognition by asking students to assess their progress, identify areas for improvement, and set goals for further learning.

Through the process of leading PBL, PrBL, and PhBL activities, the teacher's role evolves from being the sole source of information to becoming a guide, mentor, role model, and facilitator of student learning. The teacher empowers all students to take personal ownership of their learning and develop essential skills and knowledge through their own research.

5. Conclusion

According to Nobel Laureate Physicist Leon Lederman, "STEM literacy" in a knowledge-based economy is defined as the ability to adapt to and accept changes driven by new technology and work with others, often across borders, to anticipate the multilevel impacts of their actions, communicate complex ideas to a variety of audiences, and perhaps most importantly, find "measured yet creative solutions to problems which are today unimaginable" ([29], p. 3).

Integrating STEM in preK-12 classrooms naturally promotes 21CS development, especially when implemented through different variations of project-based learning

(PBL, PrBL, and PhBL) that are aligned with the 5E Model. Implementing STEM curricula requires careful planning, interdisciplinary collaborations, and a commitment to engage students in active learning. French [30] emphasized that desirable learning experiences often occur when students are engaged in something hands-on and of interest. Personalized inquiry-based experiences promote student agency shaped around student choice, kinesthetic experiences, and discussions that lead to activism, and support a lifelong learning agenda aligned with the needs of the twenty first century and beyond [31]. PBL, PrBL, and PhBL are engaging instructional approaches. Students who participate in projects tend to retain information and skills longer because they have a deeper understanding of the content through active exploration and application, and practice presenting their research. This outcome is particularly beneficial for STEM schools as it facilitates retention of students' interest in STEM subjects and encourages them to pursue STEM-related careers. STEM education raises awareness of critical issues and challenges, serving as the driver for sustainable development.

STEM disciplines are closely tied to every UN Sustainable Development Goal (the SDGs) as they equip individuals with the knowledge and skills required to address a wide range of global challenges, from education and gender equality to clean energy, innovation, and environmental sustainability. STEM education is a critical component of achieving the SDGs and creating a more sustainable and equitable world. SDG integration naturally addresses complex global challenges in a collaborative manner, leading to solutions that better address the root causes of an issue. Achievement of the SDGs is dependent upon global implementation of STEM education and the development of the essential skills needed for success in the twenty first century workplace and beyond (problem-solving, critical thinking, creativity, improved communication skills, collaboration, perseverance, information and digital literacy, and entrepreneurial skills).

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