Published by :
http://www.ijert.org

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 13 Issue 9, September 2024

Pedagogical Approach in STEM Education: A Literature Review

Latifa Rahman
Department of Administrative and Instructional Leadership
School of Education, St. John’s University, New York

Abstract

This paper discusses global educational initiatives and reforms focusing on increasing students’ engagement in STEM subjects and ensuring students are well-prepared and suitably qualified to engage in STEM education. The paper examines the contributions of the four disciplines – Science, Technology, Engineering, and Mathematics – to integrated STEM education. It discusses STEM effective pedagogical practices in STEM Education, scientific inquiry, digital learning, computer-based scaffolding, modern learning environment, computer programming, and robotics, engineering-based modeling with data, and their influences on student learning and achievement in (STEM) learning in student engagement.

***Keywords*: STEM education, pedagogy, learning, student engagement.**

INTRODUCTION

Pedagogy in Science, Technology, Engineering, and Mathematics (STEM) subjects has taken center stage globally, and education researchers are interested in how these subjects should be learned (JICA, 20134). Along with this is the need to modernize the teaching of STEM in schools through mainstreaming, utilization, and adoption of Information Communication Technologies (ICTs) (Mbugua et al., 2015) to change the way instruction has been conducted over the years and make learning more interactive and exciting to the learners. Educators, policy developers, and business and industry organizations are highlighting the urgency for improving STEM skills to meet current and future social and economic challenges (Caprile et al., 2015; Honey et al., 2014; Margison et al., 2013; Prinsley & Baranyai, 2015; The Royal Society Science Policy Centre, 2014). Bybee (2013) articulates the purpose of STEM education in a society that is STEM literate. The definition of STEM Literacy refers to an individual is:

1. Knowledge, attitudes, and skills to identify questions and problems in life, explain the natural and designed world, and draw evidence-based conclusions about STEM-related issues.
2. Understanding the characteristics and features of STEM, our material, intellectual, and cultural environments, and
3. Willingness to engage in STEM-related issues and science, technology, engineering, and mathematics ideas as a constructive, concerned, and reflected citizen.

STEM education is not just a local concern but a global movement. The interest in STEM from educational and workforce perspectives has proliferated in recent years, and the acronym was coined in the USA during the 1990s by the National Science Foundation (USA). The combination of the disciplines was seen as “a strategic decision made by scientists, technologists, engineers, and mathematics to combine forces and create a stronger political voice” (STEM et al., 2014). This global movement in STEM education is a call to action for educators, policy developers, and business and industry organizations worldwide.

STEM education is introducing more engineering during pre-college education. Engineering, focusing on problem-solving and innovation, is a crucial component of STEM education and a highly prioritized theme on every nation’s agenda (Rodger, 2010). The economic importance to society is that students should learn about engineering and develop some of the skills and abilities associated with the design process. The National Assessment Governing Board has recognized the issue’s importance and approved the evaluation of technology and engineering education through examinations given to U.S. students in 2014 (Rodger, 2010).

International concerns for advancing STEM education have escalated recently and show no signs of abating. The need for developing competencies in the STEM disciplines is urgent and should be a top priority of many education systems, fueled in part by perceived or actual shortages in the current and future STEM workforce (Caprile et al., 2015;

Charette, 2013; Hopkins et al., 2014; The Royal Society Policy Centre, 2014) and outcomes from international comparative assessments (OECD, 2013). This urgency underscores the responsibility we all share in preparing the next generation for the challenges of the future.

For future education reforms, the United States will need equal treatment for science, technology, and engineering in reauthorizing the Elementary and Secondary Act to which No Child Left Behind referred. National Academics reports Rising Above the Gathering Storm, and students must acquire such skills as adaptability, complex communication, social skills, nonroutine problem solving, self-management, and system thinking to compete in the modern economy (Rodger, 2010). The STEM curriculum group activities, laboratory investigations, and projects allow students to develop these essential 21st-century skills and prepare them to become citizens who can better decide about personal health, energy efficiency, environmental quality resource use, and national security. The competencies that students need to understand and address such issues, from the individual to global perspectives, are linked with the knowledge in STEM disciplines as they are to economics, politics, and cultural values (Rodger, 2010).

STEM pedagogies today, in efforts to developmentally prepare students for knowledge-economics and STEM fields, not only actively discourage students from seeing themselves as participants in science practices and creators of their knowledge but also commoditize the competencies to be learned following the future exchange value of those competences as workplace skills (Weinstein et al., 2016). When learners take up embedded roles as researchers, designers, and makers engaging problems and stakes critically- stakes students have agency identifying, interpreting, and co-defining – students directly engage discourses, technology tools, methods, and actions in ways that enable them to do science differently: to perform practices and develop their narratives of science and scientific doing that disrupt instrumentalized schooling enterprises: the sequenced and segmented classroom activities that too often characterize STEM education’s developmental aims (Gabriela et al., 2019).

LITERATURE REVIEW

Engaging students in high-quality STEM education requires programs to include rigorous curriculum, instruction, and assessment, integrate technology and engineering into the science and mathematics curriculum, and promote scientific inquiry and the engineering design process. All students must be a part of the STEM vision, and all teachers must be provided with the proper professional growth opportunities, preparing them to guide all their students toward acquiring STEM literacy. Educators from higher education institutions and K-12 schools can work together to develop pedagogical models that provide rigorous, well-rounded education and outstanding STEM instruction by focusing on student engagement.

Effective Pedagogical Practices in STEM Education

The following sections explore pedagogical practices that effectively promote student engagement and achievement in STEM disciplines, including inquiry-based learning, digital learning, computer-based scaffolding, modern learning environment, computer programming and robotics, and engineering-based modeling with data. STEM pedagogical practice is critical because teaching approaches are altered from traditional, teacher-centered pedagogies to active, student-centered pedagogies to support student learning (Kennedy & Odell, 2014). High-quality STEM education programs and curricula should reflect the following features:

1. Promote engineering design and program solving (scientific /engineering), identifying a problem and solving it through innovation, prototype, evaluation, and redesign—a way to develop a practical understanding of the designed world.
2. Promote inquiry by asking questions and conducting investigations to develop a deep understanding of nature and the designed world (NSTA, 2004).
3. Provide an opportunity to connect STEM educators and their students with the broader STEM community and workforce, emphasizing the importance of collaboration and real-world application. They provide students with interdisciplinary, multicultural, and perspective viewpoints to demonstrate how STEM transcends national boundaries and provides students with a global perspective, broadening their horizons and fostering a sense of global citizenship. Use appropriate technologies such as modeling, simulation, and distance learning to enhance STEM education learning experiences and investigations.

Developing STEM literacy is not just important; it is critical. It ensures that students leave school with the necessary knowledge, skills, and attitudes to engage in an increasingly technological world. The following subsections explore pedagogical practices that effectively promote student engagement and achievement in STEM disciplines, including inquiry-based learning, argumentation and reasoning, digital learning, and computer programming and robotics (Kennedy & Odell, 2014). For STEM pedagogical practices to be effective, teaching approaches must be altered from traditional, teacher-centered pedagogical to active, student-centered pedagogies to support student learning (Kennedy & Odell, 2014).

Scientific Inquiry

An inquiry approach to instruction fosters a supportive community of educators and students, where scientific discourse in collaborative groups is key. As the National Research Council (1996) states, this approach involves encouraging and modeling the skills of scientific inquiry, as well as the curiosity, openness to new ideas, and skepticism that characterize science. By preparing students to think and act like real scientists, ask questions and hypotheses, and conduct investigations using standard science practices, we create a collaborative environment where everyone's voice is heard. The definition provided by the National Research Council is stated as scientific questions, designing scientific investigations to answer questions, using appropriate tools to interpret and analyze data, formulating scientific explanations using evidence (NRC, 2012), and being able to communicate and defend relationships between evidence and scientific reasons (NRC, 2012). Students are supported in engaging in scientific discourse in collaborative groups to communicate their findings and ensure they learn to consider multiple and often conflicting perspectives on scientific problems (Clark & Linn, 2003; Linn & His, 2000).

Digital learning

Digital learning is a modern learning environment that enables students to develop their technological literacy and critical thinking skills throughout their daily learning activities (Kong, 2014). The essence of standard learning through technologies like laptops, tablets, and smartphones is in the teaching and learning process. Students can use their mobile devices to access digital learning objects and resources to support learning relevant content (Chan, 2010). Digital classrooms support the creation of constructivist STEM learning environments, which learners can conveniently access, with the teacher acting as a facilitator for knowledge construction (Kong, 2011).

Research indicates most children and adolescents engage in digital game playing, thus providing a powerful impetus to engage them in meaningful learning with relevance to their daily lives with engaging in digital game playing. That can be many positive educational outcomes have been cited by researchers regarding the effectiveness of digital game-based approaches, including facilitating independent learning, improving information processing ability, promoting higher-order thinking, developing problem-solving ability, and effectively scaffolding learning (Annetta, 2008; Mayer & Wittrock, 2006).

Computer-Based Scaffolding

Computer-based scaffolding has been regarded as an effective way to help individual students complete and gain skills at completing tasks beyond their current ability level. There has been an increased emphasis on Science, Technology, Engineering, and Mathematics (STEM) education and a shift to problem-centered instructional models to facilitate the development of these skills.

The effectiveness of computer-based scaffolding in enhancing problem-solving and other cognitive skills (Belland et al., 2017) and improving collaboration (Chen et al., 2018) is well documented. While separate synthesis efforts have confirmed the potential of computer-based scaffolding for individual and collaborative learning, and one synthesis investigated the intersection of scaffolding and collaboration support (Vogel et al., 2016), a significant gap in research remains. No synthesis has compared the use of scaffolding and collaboration support to the usage of scaffolding by itself in the context of problem-centered instruction. This underscores the urgent need for further investigation in this area, highlighting its importance in the field of STEM education and instructional design.

Modern Learning Environment

The modern learning environment is digital classrooms, which enable students to develop their technological literacy and critical thinking skills throughout their daily learning activities (Kong, 2014). Students can use their mobile devices to access digital learning objects and resources to support learning relevant content (Chan, 2010). Digital classrooms support the creation of constructivist access and develop and share relevant knowledge on a progressive basis, with the teacher as a facilitator of knowledge construction (Kong, 2011).

Computer Programming and Robotics

The transformative pedagogical approach that has garnered increasing attention revolves around the integration of computer programming and robotics across schooling (Israel et al., 2015). It's a shift from the traditional focus on operating technologies as end-users to a more innovative approach to learning to develop new technologies (Kafai et al., 2014). In this pedagogical paradigm, creation, computer programming, and robotics are not just tools, but learning technologies that can foster competencies, such as problem-solving and higher-order thinking skills (Fessakis et al., 2013).

The process is multidimensional and iterative and comprises several phases, including framing problems in a manner that enables them to be solved using computational tools; organizing and analyzing data; using models and simulations to represent data; implementing algorithmic thinking to automate solutions; evaluating the resolution, and implementing the problem-solving process to other contexts. Engaging students in computer programming experiences benefits their learning, attitudes, and motivation (Lambert & Guiffre, 2009; Liao & Bright, 1991). For example, simple computer programming activities have been shown to facilitate learning with kindergarten children (Fessakis et al., 2013).

They were participating students in robotics, a highly effective pedagogical practice, particularly in programmable and interactive robotics (Bers et al., 2014). Engaging in robotic manipulatives has been shown to develop problem-solving skills, fine motor skills, and hand-eye coordination (Bers, 2008). Play, a highly valued aspect of the early childhood curriculum, is a source of joy and excitement. Engaging children in robotics activities allows them to play and learn in a creative environment, fostering their love for learning (Resnick, 2003). It is essential to provide opportunities for students to engage in computer programming and robotics from the start of their schooling to develop their computational thinking skills. Some other studies highlighted the importance of developing other competencies, such as core mathematical understanding in early childhood, to engage students in learning and bolster student achievement (Claessens & Engel, 2013).

Engineering-based modeling with data

Modeling with data addresses the mathematical literacy domain that comprises important learning features that facilitate different integration, including the interdisciplinary and transdisciplinary approaches (Lyn, 2016). The data involves several elements supporting engineering within integrated STEM approaches, including design processes, problem-solving and thinking, testing, receiving, and improving generated products. Features of modeling with data (adapted from English, 2015)

1. Exploring, posing, and refining investigative questions within STEM contexts.
2. Applying discipline-based concepts and engineering design in formulating and solving problems.
3. Testing, revising, and improving products generated.
4. Planning and undertaking investigations.
5. Analyzing and representing data in multiple ways.
6. Critically evaluating data-based arguments and conclusions.

Students' reasoning in working on the problem illustrated how they drew upon multiple disciplinary features. For instance, in a STEM project that involves designing and building a model bridge, students would draw upon their knowledge of physics to understand the forces acting on the bridge, their mathematical skills to calculate the dimensions, and their engineering design skills to construct the bridge. This reflects Charette's (2014) view on STEM integration: "If we truly want students who can think critically, solve problems, and communicate their thoughts clearly, then some systematic, cross-disciplinary instruction is not just beneficial, but necessary.

CONCLUSION

An overview of the state of STEM education allows us to make some general conclusions. The article indicates the concentration on the pedagogy of STEM education with the curriculum for the student's training and retraining educators and practitioners involved in education. The authors suggest that the key to preparing STEM educators is to begin by grounding their conceptual understanding of STEM education in student engagement. STEM education is, therefore, an innovative pedagogy that presents enormous opportunities for technology education researchers. The opportunity involves establishing STEM design experiments that may be used to investigate a wide range of conjectures and modest approaches regarding STEM learning pedagogy that situates STEM learning in the context of authentic technological design-based problem-solving. This collaborative nature of STEM education makes everyone feel connected and part of a larger community.

REFERENCES

Annetta, L. A. (2008). Video games in Education: Why they should be used and how they are being used. Theory into practice, 47(3), 229-239.
Bybee, Rodger, W. (2013). The case for STEM Education: Challenges and opportunities. National Science Teachers Association, NSTA Press, Arlington, Virginia.
Belland, B. R., Walker, A. E., & Kim, N. J. (2017a). A Bayesian network meta-analysis to synthesize the influence of contexts of scaffolding use on cognitive outcomes in STEM education. Review of Educational Research, 87(6), 1042–1081. Retrieved from https://doi.org/10.3102/0034654317723009.
Chan, T. W. (2010). How East Asian classrooms may change over the next 20 years. Journal of Computer Assisted Learning, 26(1), 28–52.
Chen, J., Wang, M., Kirschner, P. A., & Tsai, C.-C. (2018). The role of collaboration, computer use, learning environments, and supporting strategies in CSCL: A meta-analysis. Review of Educational Research, 88(6), 799–843. https://doi.org/10.3102/0034654318791584.
Caprile, M., Palmen, R., Sanz, & Dente, G. (2015). Encouraging STEM studies for the labor market (Directorate-General for Internal Policies: European Parliament).
Clark, D., & Linn, M. C. (2003). Designing for knowledge integration: The impact of instructional time. The Journal of the Learning Sciences, 12(4), 451-493.
Chan, T. W. (2010). How East Asian classrooms may change over the next 20 years. Journal of Computer Assisted Learning, 26 (1), 28–52.
Charette, R. N. (2013). The STEM crisis is a myth. Retrieved 23 December 2014 from http://spectrum.ieee.org/at-work/education/the-stem-crisis-is-a-myth.
Charette, R.N. (2014). Commentary: STEM sense and nonsense. Educational Leadership, 79-83.
Gonzalez, H.B. & Kuenzi J. (2012). Congressional Research Service Science, Technology, Engineering, and Mathematics (STEM) Education: A Primer, p. 2. Retrieved from http://www.stemedcoalition.org/wp-content/uploads/2010/05/STEMEducation-Primer.pdf
Gabriela A. Yanez, Kurt T., Suzanne D. C., Jennifer J. (2019). Pathways to sustainable futures: A "production pedagogy" model for STEM education. Elsevier.
Honey, M., Pearson, G., & Schweingruber, A. (2014). STEM integration in K-12 education: status, prospects, and an agenda for research. Washington: National Academies Press.
Hopkins, S., Forgasz, H., Corrigan, D., & Panizzon, D. (2014). The STEM issue in Australia: What it is and where is the evidence? Paper presented at the STEM Conference. Vancouver, Canada (http://stem2014.ubc.ca).
JICA Report (2013). Kenya SMASSE/SMASSE project (1998-1013). Nairobi. Kenya.
Kong, S. C. (2011). An evaluation study of using a cognitive tool in a one-to-one classroom for promoting classroom-based dialogic interaction. Computers and Education,57(3), 1851-1864.
Kong, S. C. (2014). Developing information literacy and critical thinking skills through domain knowledge learning in digital classrooms: An experience of practicing flipped classroom strategy. Computers & Education, pp. 78, 160–173.
Lyn D. (2016). STEM education K-12: perspectives on integration. International Journal of STEM education. Springer.
Marginson, S., Tytler, R., Freeman, B., & Roberts, K. (2013). STEM: country comparisons. Melbourne: Australian Council of Learned Academies.
Mayer, R. E., & Wittrock, M. C. (2006). Problem solving. Handbook of educational psychology, 2, 287-303.
Mbugua, Z., Kibet, K., Muthaa, G., & Nkonke, G. (2012). Factors contributing to students' poor performance in mathematics at Kenya certificate of secondary Education in Kenya: A case of Baringo county, Kenya, Aijcrnet.com, 2(6), 87-91. Retrieved from http://aijcrnet.copm/journals/vol_2_No6_June_2012/11.pdf.
McNeill, K. L., Pimentel, D. S., & Strauss, E. G. (2013). The impact of high school science teachers' beliefs, curricular enactments, and experience on student learning during an inquiry-based urban ecology curriculum. International Journal of Science Education, 35 (15), 2608-2644
NRC (2012). National Research Council. A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas. Washington, DC: The National Academies Press
Kennedy, T. K., & Odell, M. R. L. (2014). Engaging students in STEM Education. Science Education International, 25(3), 246–258.
Kong, S. C. (2011). An evaluation study of the use of a cognitive tool in a one-to-one classroom for promoting classroom-based dialogic interaction. Computers and Education, 57(3), 1851-1864.
Kong, S. C. (2014). Developing information literacy and critical thinking skills through domain knowledge learning in digital classrooms: An experience of practicing flipped classroom strategy. Computers & Education, pp. 78, 160–173.
Prinsley, R., & Baranyai, K. (2015). STEM skills in the workforce: What do employers want? Occasional Papers Series, issue 9, March. Office of the Chief Scientist.
The Royal Society Science Policy Centre. (2014). Vision for science and mathematics education. London: The Royal Society.
OECD (2013). PISA 2012 assessment and analytical framework: mathematics, reading, science, problem-solving, and financial literacy. OECD Publishing (http://www.oecdilibrary.org/content/book/9789264190511-en).
Rodger W. Bybee (2010). What is STEM Education? Science Magazine. Vol 329, Issues 5995. DOI: 10.1126/science.1194998
STEM Task Force Report. (2014). Innovate: a blueprint for science, technology, engineering, and mathematics in California public education—Dublin, California: Californians Dedicated to Education Foundation.
U.S. Council of Advisors on Science and Technology (2010). Prepare and Inspire K-12 Education in Science, Technology, Engineering, and Math (STEM) for the Future. Retrieved from http//www.whitehouse.gov/sites/default/files/microsites/ostp/pcaststem-ed-final.
Vogel, F., Kollar, I., Ufer, S., Reichersdorfer, E., Reiss, K., & Fischer, F. (2016a). Developing argumentation skills in mathematics through computer-supported collaborative learning: The role of transactivity. Instructional Science, 44(5), 477–500. https://doi.org/10.1007/s11251-016-9380-2.
Weinstein, M., Blades, D., & Gleason, S.C. (2016). Questioning power: Defaming the STEM discourse. Canadian Journal of Science Mathematics and Technology Education, 16(2), 201–212.