STEM Education Review

REVIEW ARTICLE

STEM education and the project-based learning: A review article

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ABSTRACT

National economic development is shifting from industrial sectors such as mining, and agriculture, amongst others, to prioritizing Science, Technology, Engineering, and Mathematics (STEM) en route to building new jobs, creating growth, and driving innovation. Different nations have made significant moves to invest in STEM education primarily driven by the need to foster human resources, henceforth creating specialized schools focused on STEM fields. These schools need to couple academic learning with its application to real-world contexts and problems through project-based learning (PBL). However, while implementation and evaluation have been the subject of many studies, there is still a dearth of studies that involve evaluating the implementation of PBL as a pedagogical approach in teaching research curricula in STEM schools.

Key words: STEM education, project-based learning, STEM high school

INTRODUCTION

The context of a nation, including some indicators such as wealth, education, power, religion, and language, among others, aligns with its focus in research.[1] Some nations' research focus is driven by altruistic (such as societal good, health, and quality of life) motive while some nations are driven by economic motivations (such as science and technology).

The success of a country's economy largely depends on its ability to innovate.[2] Improved productivity, partly due to innovation, has been credited with a substantial amount of many developed countries' economic development. Hence, to ensure that innovation and productivity continue to grow, a surfeit number of human resources equipped with Science, Technology, Engineering, and Mathematics (STEM) skills will be needed to drive these economic processes. Now, many nations' national economic development is shifting from industrial sectors such as mining, and agriculture, amongst others, to prioritizing STEM en route to building new jobs, creating growth, and driving innovation.[3] With this shift, new industries and sources of profit for the economy arise, including the emergence of new digital technologies necessitating the acquisition of new STEM abilities. STEM, therefore, is becoming a "major emphasis in global initiatives seeking to enhance economic prosperity *via* a highly educated workforce".[4,5]

Many countries, therefore, made significant moves to invest in STEM education primarily driven by the motivation of the need to foster human resources. These are human resources who are ready to undertake science and technology-related careers.[5,6] Many initiatives and efforts have been instigated to significantly boost the number of students interested in various STEM fields. Doing so will ensure that fully equipped and competent human resources will fill up the STEM professions and jobs in the future. Efforts have been attempted and

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successfully implemented to integrate STEM education into the system and create specialized schools focused on STEM fields.

This review aims to advance research by providing a synthesis of STEM education literature to highlight and point to research gaps that deserve further research, particularly on specialized STEM High School and its implementation of project-based learning (PBL) and research education.

SPECIALIZED STEM HIGH SCHOOL AND PROJECT-BASED LEARNING

Specialized schools are meant to satisfy the requirements of learners who have interests and talents in a specific academic topic, even though they are not usually explicitly designated for gifted and talented students.[7] Specialized schools for learners with excellent math and scientific potential are relatively new phenomena.[8] To prepare learners for the industrial workforce, the United States Department of State, for example, established technical high schools like Stuyvesant High School and Brooklyn Technical High School. Other specialized schools like Juilliard were put up for the gifted and talented in the fine arts.

Choice and control over one's academic experiences are essential qualities of a school that fulfills the demands of a group with abilities and interests.[9] Most specialized STEM institutions are schools of choice. They actively involve students' natural interests in the pursuit of coursework, which is a critical component of engagement and motivation.

While STEM-focused specialty schools are of current study interest, their presence has been documented for more than a century. These institutions have been referred to as "specialized Science, Mathematics, and Technology (SMT) schools" or simply "specialized schools" in the past.[7,10,11] In response to the political, educational, and economic drifts, secondary schools specialized in science and technology were erected.[7] Following World War II, countries like the US began to establish specialized scientific high schools to support the development of future scientists and engineers. In the early twentieth century, such institutions did not improve skills or create chances for the exceptional and talented but to train a workforce with specialized technical abilities. The requirement for a competent workforce is reflected in the roots of the specialized STEM high school.

STEM high schools provide a rigorous education for developing science aptitude.[12] These institutions provide students inclined in mathematics and sciences with increased learning opportunities through an advanced curriculum that stresses a deeper grasp of the sciences and mathematics. Further, the definition of STEM education is explained as follows.

STEM education is an interdisciplinary approach to learning where rigorous academic concepts are coupled with real-world lessons as students apply STEM in contexts that make connections between school, community, work, and the global enterprise enabling the development of STEM literacy and with it the ability to compete in the new economy.[13]

This emphasizes the need for couple academic learning with its application to real-world contexts and problems. Furthermore, specialized schools combine advanced curriculum with significant immersion in authentic work in these fields. Therefore, this "authentic work" puts a significant emphasis on implementing PBL approach in STEM schools.[10] PBL has been a central pedagogical approach as it aligns with the goals of STEM education.

One of the advantages of a STEM focus over traditional teaching methods is the suitability of PBL as a pedagogical approach.[11] The PBL is at the top among the eight elements equating with STEM schools' key educational goals.[13] By definition, PBL aims to be student-centered, allowing students to study a subject or a topic while collaborating with others to solve an issue or problem they identify from their community or society.[14] Furthermore, the core idea of PBL is that real-world problem capture students' interest and provoke serious thinking as the students acquire and apply new knowledge in a problem-solving context. Advocates assert that PBL helps prepare students for the thinking and collaboration skills required in the workplace.[15]

Showing improvement in students' understanding of science, development of problem-solving and collaborative skills, and arithmetic skills, PBL has been advantageous over the use of traditional methods.[16] The problem students identify from their society or community is the driver of their learning in PBL.

PBL is an instructional approach that emphasizes active learning through real-world projects.[17] Instead of traditional lectures and exams, students engage in collaborative projects that require them to apply their knowledge and skills to solve complex problems or create something tangible. PBL as an integral approach in STEM high school creates an effective STEM education as it enables authentic learning, an interdisciplinary approach, skills development, and student engagement.

Authentic learning

PBL in STEM education creates an authentic, real-world learning experience. with PBL, students are engaged in hands-on projects allowing learners to directly apply STEM concepts in practical settings, mirroring the challenges and problem-solving skills required in STEM careers.

Interdisciplinary approach

With STEM along, STEM high schools integrate multiple disciplines including STEM in their curriculum. what combines these subjects effectively is utilizing PBL as a pedagogical framework. Hence, students can work on projects that require them to draw knowledge from various STEM fields and concepts, promoting a holistic understanding of how the intersect.

Skills development

The aim of STEM high schools is to develop several skills and capabilities in students which includes critical thinking, problem-solving, collaboration, and communication. PBL, as an approach, inherently cultivates these skills as learners identify and delve into complex problems, work with their peers, mentors, and other professionals, and communicate their findings to the community. Engaging learners in hands-on work helps students develop these practical skills, and allowing them to utilize these skills in their future STEM careers.

Student engagement

PBL in STEM education provides learners autonomy and ownership of their learning through their projects as they become active participants in this education process. This approach, therefore, can intensify students' interest in applying STEM concepts in their own-identified problems, in turn, encouraging lifelong learning.

Different countries have long seen the value of integrating PBL. In the US, PBL programs have been widely used in various high schools identifying the major benefits it results in community partnership, authentic projects, and school culture, among others.[18] PBL has become so successful in America that one school in Washington is spending 128 million dollars on rebuilding its campus and redesigning its curriculum around the teaching technique.[19] Chinese universities integrating the PBL approaches saw high agreement for its use due to its self-directed learning, teamwork, and peer-review assessment features.[20] The PBL paradigm utilized at Aalborg University in Denmark allowed engineering students to handle sustainability-related projects, interplay and mix, and diversity.[21] In the UK, PBL is called "Independent Learning", it is "hugely significant as a concept and is massively understood".[22]

In the Philippines, the use of PBL as an educational approach is not new. A study was dedicated to understanding the experiences of the eight medical schools that have adopted PBL.[23] The study found that positive attitude of administrators, faculty, and students in the use of the PBL which they saw a move for innovation and change. The study also found that graduates of PBL schools performed better overall as compared to those who graduated from non-PBL schools.[23] Learners from Indonesia and Philippines improve their learning process with the integration of PBL in problem solving activities.[24] Filipino high school students have shown enhanced critical and creative thinking skills with the implementation of PBL in Biology,[25] increased problem-solving skills in Chemistry concepts,[26] and became a viable and flexible alternative to traditional intensive English coursework.[27]

The Philippines' leading STEM high school system, the Philippine Science High School (PSHS) System, was established in order to provide quality STEM education to young Filipinos who are gifted in science and mathematics.[28] The PSHS aims that these young Filipino learners will grow to become future scientists, engineers, and researchers, and in turn, contribute to the country's advancement in science and technology. Furthermore, with its 6-year curriculum, PSHS System is known for its strong emphasis on scientific research, therefore cultivating a culture of research among its scholars.

In the PSHS System, PBL complements the research culture by providing various opportunities to apply the students' knowledge and skills in science in practical settings. The system also organizes research fairs, competitions, and symposiums to showcase students' research work and foster a culture of scientific inquiry. This is proven by the PSHS campuses' achievements in various national and international research competitions have undoubtedly brought honor and pride to the country.[29] With these excellences, one can undoubtedly say, therefore, that the PSHS System has been successful in the implementation of its curriculum particularly the one that focuses on the research education of the students which is anchored on the tenets of the PBL.

Overall, PSHS aims to instill a strong research culture and promote PBL to develop well-rounded students who are equipped with the necessary scientific skills and mindset to make significant contributions in their respective fields.

With the portrait of STEM education and PBL,[30,15] students must engage with relatable but rigorous problems. This will allow students to think critically and apply their knowledge to real-world problems, allowing them to solve them. Critical thinking skills were significantly improved by using a project-based approach to advance learners from beginning to advanced and practicing thinkers, allowing them to "critique their own plan for systematic practice, and to construct a realistic critique of their powers of thought to solve the contextual problems".[31]

Engaging students in PBL proved the improvement of their science process skills. This allows learners to be immersed in actual-world problems that they identify at the onset of their course and thereby allowing them to utilize fundamental and integrated science process skills. Improvement in these skills has been noted as learners are engaged in scientific inquiry brought about by implementing a PBL model.[32]

Students learn basic and integrated science process skills, usually in science courses. With basic science process skills, students apply the principle of the scientific method by observing, measuring, classifying, inferring, predicting, and communicating. Higher forms of these skills, the integrated science process skills, enable the learners to develop their skills in identifying and defining variables, formulating hypotheses, designing research, experimenting, and collecting and analyzing data. These science process skills "form an important part of scientific inquiry and promote scientific literacy among students".[33]

NEED FOR CURRICULUM REVIEW

The integration of PBL as an approach to STEM education curriculum can enhance authentic learning, student engagement, and promotion and development of capabilities and skills.[34] Its implementation, therefore, requires a curriculum review to assess the extent of its implementation and level of effectiveness within unique contexts of various STEM high schools. The persistent question facing STEM schools implementing PBL through their research curricula is "How can we appraise the effectiveness of this approach in STEM curricula: what aspects of the program do we need to evaluate to establish the extent of its success in upbringing the future STEM professionals of the country".

Curriculum evaluation, therefore, is an important aspect for educational implementers to provide the basis for policy decisions and, in turn, give feedback for continuous adjustments of the curriculum in areas that need improvement. The basic areas of concern in implementing curriculum evaluation are: (1) how effective and efficient government education policies are being translated into educational practice, (2) what is the status of the curriculum learning contents and experiences are in the local, national, and international contexts, and (3) what is the extent of achievement of objectives set for the curriculum.[35]

There are three types of decisions for which curriculum evaluation is often utilized.[36] They are course improvement, decisions about individuals, and administrative regulations. Course improvement decides what teaching-learning materials and methodologies are worth sustaining and which need to be changed. Secondly, the decisions about individuals identify the learners' needs in planning classroom instruction and grouping, thereby allowing these learners to identify their deficiencies. Lastly, the administrative regulations appraise the school system and individual teachers' performance. Ultimately, the goal of curriculum evaluation is to facilitate the selection of educational activities and materials, their adoption, and embedding into the curriculum.

RESEARCH GAP AND RESEARCH QUESTIONS

There is a need for more studies that evaluate the implementation of PBL as a pedagogical approach in teaching research curricula in STEM schools. Studies centered primarily on the importance of PBL in specific STEM subjects other than in the research course. The absence of relevant studies focused on facets of PBL as applied in research education has been noted. Hence, without a curricular evaluation, decisions to select, adapt, embed, and support pedagogical approaches and continuous improvement of the implementation of PBL in STEM schools through research courses may be impeded. Hence, this can bring future research to answer the questions, "How is project-based learning implemented in research education?" and "How effective is the project-based learning approach in learning the concept of doing research?"

While the content of the curriculum is important to be assessed, other curricular aspects should likewise be evaluated. The assessment of the curriculum's leading actors, that is, the teachers, will give an important insight as to how the curriculum will be effectively implemented. A substantial number of works have been dedicated concerning the impact of teachers on the academic achievement of learners. Much of these works, however, have zoomed in on the teachers' knowledge of the subject matter[37,38] and the teacher's choice of pedagogical approaches.[39] However, another pressing discussion that needs to be the source of an academic dialogue is the decisions curriculum implementers make about how conceptual and procedural knowledge are to be implemented in the classroom. Also, while there is a cache of research that deals with the implementation of conceptual and procedural knowledge in teaching, most if not all of the available literature only deals with its implementation in mathematics education.[40–43] There is a lack of available and substantial studies on how the two types of knowledge are applied in facilitating PBL in the teaching of the research curriculum. Mainly, there is a need to understand if, from the perspective of the educators, conceptual knowledge outweighs the need to develop the procedural knowledge of the gifted learners in the teaching of a research curriculum. Future research can answer the question, "What is the level of conceptual and procedural teaching of teachers handling the research courses?"

PSHS System, as discussed in the earlier section, has been at the forefront of bringing pride to the country for its achievement in research. However, equity in the number of research competitions being involved with and competitions won is not apparent among campuses of the PSHS System. Many of these local and international competitions are dominated by specific campuses. Furthermore, previous research showed a dismal successful implementation of PBL on the side of the Department of Education specialized science high schools as perceived by the teachers across various regions of the country who are involved in implementing the research curricula.[6] Hence, an evaluation of such an approach on the side of the Department of Science and Technology's PSHS System research program should be conducted, which leaves one to ask, "What is the current status of research education in the different campuses of the Philippine Science High School System?"

Developing and improving a balanced curriculum, both its contents (including the learning experiences and evaluation methods) and the key players of its implementation, is extremely important, enabling learners and teachers in many aspects.

DECLARATION

Author contributions

Dacumos L: Conceptualization, Writing—Original draft, Writing—Review and Editing, Investigation.

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