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THE ROLE OF STEM LAB EXPERIMENTS IN BUILDING SCIENCE LITERACY IN CHEMISTRY EDUCATION

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ABSTRACT

This article brings out how much the role played by STEM laboratories boosts science literacy, with particular reference to chemistry. It looks at how this experiential learning reconciles the disparity that always exists between abstract theoretical views and practical understanding, hence enhancing effective appreciation of complex scientific principles. By conducting experiments in a laboratory, students receive the most crucial aspects to become successful in their academic and working career in STEM. This paper goes further to show an insight on how these hands-on experiences increase student involvement, motivation and create an environment that encourages working together; something taken to be parallel to what is involved in scientific research working. This paper also goes into how equipping STEM labs with cutting-edge technologies like virtual simulations and the corresponding digital tools would be like. These technologies do not only support learning but also fully prepare students for the now highly technological and digitized modern landscape of science and industry. It is about the creation of a scientific and creatively competent generation of thinkers who ought to provide a solution to most of the problems that face the globe in the 21st century. The global workforce requirements now carry new emphasis on science, technology, engineering, and mathematics. Therein, educational systems need to alter themselves to fit that bill. Without proper incorporation of lab-based learning, the paper argues, we cannot be in a position to prepare and equip our students for a future that will require both scientific knowledge and technological proficiency.

Keywords: *STEM education, science literacy, chemistry education, lab experiments, student engagement.*

1. Introduction

STEM education is becoming one of the most important education requirements in today's educational context. Unlike traditional pedagogical models, STEM education is not about the transmission of technical content, but it is essentially oriented to prepare students for addressing the critical demands of the 21st century. The said competencies, often referred to as "4Cs" in general — creativity, critical thinking, collaboration, and communication—would be necessary to succeed in any area of application, whether in service or personal (Morisseau et al., 2023). In addition to these core competencies, the STEM framework further cultivates adaptability or the ability to be flexible in different situations, and resilience, which has been highly valuable in the modern world as the pace of other developments and societal challenges pick up quickly. Other than that, STEM is interdisciplinary, and from that, students will very likely acquire a sense of connecting the dots across disciplines. It results in holistic problem-solving ability crucial to innovation in the connected world of today (Daugherty, 2017).

All these connect to another core purpose for providing STEM education: science literacy. Much more should be said in this connection than simply conveying an understanding of scientific facts; such understanding enables the learner to develop the abilities to appraise information, make decisions with a scientific basis, and be part of discussions on issues in science that govern society (Raykova, 2019). In this light, science literacy plays a key role when we are handling nominative issues at the global level such as climate change and public health crises that empower us to make meaningful decisions and contribute towards enhancing better social well-being according to Martin (2013). In an information epidemic, the skills of identifying credible sources and understanding the scientific method are critical to any relevant public discourse and policy. Science literacy is important as it permits the public to engage in debates on environmental sustainability, health, and the regulation of technology to ensure that different perspectives are used to build on a base of sound scientific principles (Howell, 2021).

Another sizable push is that of STEM literacy for all students, regardless of background, as a basic building block for equity in education. It means that every student is given the chance to succeed by obtaining fundamental knowledge that will enable them to thrive in the modern world. As cited by Jackson, Mohr-Schroeder, Bush, et al. (2021), STEM is about not only giving everyone an opportunity but also about fixing the systemic barriers that have essentially excluded certain groups. In this way, educators can facilitate the closing of differences in the STEM fields and increase diversity in the workforce by being more inclusive of students from underrepresented backgrounds in the field of study (Jackson, Mohr-Schroeder, Bush, et al., 2021). Moreover, this will provide an equitable STEM education that enables all students to participate in a rapidly globalizing economy, where technological fluency and scientific literacy are viewed as increasingly relevant skills in reducing socio-economic inequalities and rising social mobility (Dare et al., 2021; Khadri, 2022; Marzuki, 2024).

As part of STEM, chemistry represents an individual resource base that tries to advance science literacy. Chemistry education enhances understanding of the natural world and provides applications integral to a number of industries, from pharmaceuticals to environmental science. It is basically based on the principles of chemistry that underlie much of the technologies and processes driving modern society today. Many of the concepts of chemistry may, however, remain abstract to the students (Osman, 2013). This is where the STEM lab experiments play a very vital role. These experiments connect theoretical knowledge and practical understanding in a hands-on way to the students by enhancing their overall science literacy (Martin, 2013). Laboratory experiments also allow the students to be curious and experiment with concepts in a controlled environment, as they can directly see the association of actions with the outcomes. This kind of experiential learning consolidates abstract concepts, therefore easier to access and understand, which means deeper understanding in the subject area (Sasapan et al., 2024).

The paper contributes to the discourse on the effects of STEM lab experiments in science literacy in chemistry education. It elaborates on how such hands-on experiences develop important skills and increase their engagement on the way to become very vital in fostering innovative thinking and problem-solving. This importance makes the integration of innovative lab experiences into STEM curricula quite relevant, aimed at helping students comply with new requirements that are undoubtedly expected of them from the workforce. Students having a strong STEM foundation, together with laboratory experience, feel encouraged with the confidence to address challenges of the future and contribute — advisedly — to the advancement of society.

2. The Intersection of STEM and Chemistry Education

Chemistry is one of the central field disciplines of science and occupies a central place in STEM education. This central nature can be seen in its description of the composition, structure, properties, and changes associated with matter forming the basis of a number of scientific and industrial processes. Chemistry is a subject operating on two levels: it stands alone in the realm of STEM and acts as an integrative force, helping to interlink with other STEM fields and further interdisciplinary in learning and innovation.

Chemistry as a Core STEM Subject

Chemistry is often referred to as the "central science" because it bridges, for example, physics and biology with other natural sciences (Brown, LeMay, & Bursten, 2009). It enables the molecular level of understanding that has underlain many of the major advances in medicine, environmental science, and materials engineering. Being a basic STEM discipline, chemistry education would be expected to provide students with transferable critical thinking and problem-solving skills for application in a variety of STEM careers. The chemistry education, according to Almesh and Meirmanova (2023), not only helps in understanding the complex concepts but also offers scope for the development of analytical skills, making it important for the completion of education in STEM fields. The following study further reinforces that chemistry in STEM is mostly about developing cognitive skills for innovation and technological progress, and not only about knowledge (Almesh and Meirmanova, 2023).

Moreover, the place of chemistry in STEM education is very relevant to many contemporary global challenges related to climate change, sustainable energy, and health. For example, green chemistry — in its application of the principles of designing products and processes to minimize or avoid the use and generation of hazardous substances — finds a lot of room for inclusion in STEM education (Anastas & Eghbali, 2018). The approach aids in developing a knowledge base of the students in the sphere of chemistry while shaping a sense of responsibility toward sustainable development.

Lab Experiments in Chemistry

The laboratory is the most important component of chemistry education. Its hands-on experiences add a vital understanding of theoretical concepts (Abrahams, Reiss, & Sharpe, 2013). Such experiments would thus allow students to observe chemical reactions, analyze the results, and draw conclusions. As Hofstein and Lunetta (2004) said it, laboratory experiments in chemistry education inject a lot of energy in students to understand the scientific concepts and on the other hand build up their investigative approaches toward life. The authors noted that practical work undertaken by the students in the laboratory will help them relate different abstract concepts learned in the classroom to real phenomena, hence making the learning process very engaging and effective (Hofstein and Lunetta, 2004).

Experiments in inorganic chemistry laboratories are integral parts of laboratory coursework, which result in a student better understanding the chemical principles learned in classrooms and critical skills development in data interpretation and problem-solving. These skills are quite relevant to students who will pursue their careers in the chemical sciences but are generally transferable to other STEM fields. Well, the argument of Abrahams and Reiss (2012) is that the regularly involved students used to have the highest levels of reasoning in science, as well as the best ability to transfer theoretical knowledge into practical situations (Abrahams and Reiss, 2012).

Further, in-class laboratory experiments offer students the opportunity to learn collaboratively since much of the work is student-centered and focused on group work and discussions (Cooper & Kerns, 2006). Collaborative nature of lab work will further enhance the development of communication and teamwork skills, very basic for STEM careers. Chemistry education can gain from laboratory experiments assuming collaborative learning in nature — one in which the students are empowered to share ideas, challenge assumptions, and solve problems as one unit (Buck, Bretz, & Towns, 2008).

Scientific literacy

Scientific literacy is a modern focus in science education, emphasizing the development of knowledge, skills, and competencies essential for solving everyday problems. This often becomes a critical focus for success in personal and professional development and is important for the social integration of a person. One of the main goals in science education today is that of achieving scientific literacy, which can be achieved by implementing various methods and tools all aimed at conforming to modern trends in education. Conducting lessons in the context of achieving such goals is quite variable according to the methods and tools that can be used for all types of lessons and forms of education, where practically every method can be adapted for the purpose of fostering scientific literacy.

According to Prenzel (2001) and Fischer (1998), scientific literacy includes understanding fundamental scientific concepts and phenomena, recognizing the stages and nature of scientific work. It is essential to have basic knowledge of the structure and essence of science, and to understand the relationships between science, technology, and society (Raykova, 2008). Miller (2001) describes scientific literacy as a three-dimensional structure that encompasses knowledge of basic scientific terms. These terms are sufficient for understanding popular scientific articles, processes, methods, and awareness of the impact of science and technology on individuals and society (Miler, 2001).

Holbrook and Rannikmae (2007) compare the scientific literacy with much more than the acquisition of the scientific system of knowledge and methods needed to obtain this. It includes the grasp of basic principles of science (Holbrook & Rannikmae, 2007). It is essentially a mixture of concepts, history, and philosophy. This knowledge enables an SCL person to explain phenomena that surround their daily life, understand new items that involve science, and make personal decisions on civic/cultural as well as socio-economic productivity issues. A scientifically literate citizen is capable of describing, explaining, and predicting natural phenomena. The authors relate science literacy to knowledge of the nature of science and attitude toward personal growth and concern for social values (Holbrook & Rannikmae, 2009).

Scientific literacy is crucial because it offers a framework for addressing social issues. Scientifically literate populations are better placed to handle many of their problems and make informed decisions that will affect the lives of themselves and future generations. Science education strategies should not seek to recruit future scientists but should be aimed at enhancing public scientific literacy with an interdisciplinary approach.

3. How STEM Lab Experiments Enhance Science Literacy

STEM lab experiments form part of the learning process, especially in sciences, where they provide a core tool for the development of science literacy (Sampson, Grooms, & Walker, 2011). Scientific literacy goes beyond knowledge of science facts; it embodies the ability to apply reasoning in science, to understand the processes involved in science, and to make informed decisions about issues confronting society (Norris & Phillips, 2003). Laboratory experiments are, therefore, very key in the development of these skills by providing each student with practical experience that helps link theory with practice.

One of the major contributions that STEM laboratory experiments do for developing science literacy is to build students' skills in critical thinking and problem solving. Often the students design experiments, make observations, and record data, analyze it, and finally draw some inferences or conclusions based upon those findings. These processes often form the methodology that was used with the scientific method, so students think very critically about all the information they work with. According to Hofstein and Lunetta (2004), students who go through lab experiments are better equipped with the abilities of data analysis and interpretation, in which scientific literacy is inductively built. These skills are not only valid for science but also hold relevance in daily life, where one has to deal with information critically (Hofstein and Lunetta, 2004).

The STEM lab experiments add up, especially where there is a need to make the abstract theories more practical. In chemistry, for most students, it is an uphill task to visualize interactions between molecules or difficult in understanding complex theories only written in the textbooks. Learners are better positioned to observe some chemical reactions taking place as a result of varying different variables while conducting lab experiments. Abrahams and Millar (2008) also argued along this line, saying that this experiential learning made the students understand and retain the scientific knowledge. They noted that students who engage in experimental activities are more likely to grasp and remember complex scientific concepts (Abrahams and Millar, 2008).

Other important effects of STEM lab experiments involve their potential to increase students' engagement and motivation. Most of the time, conventional classroom settings are filled with a high degree of lecturing or 'textbook learning'; sometimes it leads to passiveness on the part of the student, which certainly is not needed. Lab experiments demand active participation, hence building a more engaging environment in learning. Freeman et al. (2014) established the relationship between active learning involving laboratory work and students' achievement on STEM disciplines. Laboratory experiments enrich learning activity by engaging students in practical activities, which will most likely trigger a more significant interest in the subject matter and a deeper commitment to the pursuit of science-related fields (Freeman et al, 2014).

Lab experiments are essential inquiry-based, allowing students to ask questions, explore possibilities, and find answers in the laboratory. This process of scientific inquiry underpins science literacy. Through such inquiry-based learning processes, students develop deeper insights into how science works and a greater curiosity about the natural world. This leads to further searching for knowledge, after which the learning process creates a positive cycle that improves science literacy. According to Anderson (2002), inquiry-based lab work enables students to acquire an investigating and discovering perspective toward objects, situations, or phenomena — which is a very important element in these classes when trying to nurture an interest in science throughout life (Anderson, 2002).

4. CONCLUSION

STEM lab experiments strongly improve science literacy. These labs, in a constant efficient manner, can link the theoretical part with the practical learning aspect. Therefore, such hands-on activities develop critical thinking, problem solving, and analytical skills, hence making scientific concepts more accessible and appealing to students. Labs increase motivation, curiosity, and deeper understanding of scientific literacy by involving the student in an active learning process. They are also arming them with practical skills necessary in a real STEM career and creating a scientifically literate society that is empowered and better placed to meet the challenges that come their way. Several technologies, like virtual labs, AI, and simulations, will only further amplify this effect that lab experiments have on STEM subjects such as chemistry. It will further activate, engage, and individualize learning activities in chemistry education for all to be more inclusive and effective. If STEM in chemistry education is going to harness these new technological developments, then there will be a bright future for the students in order to become prepared against the fast-changing world. If a generation with a scientific way of thinking is to be created, emphasis by educators, institutions, and policymakers should be put on the integration of STEM laboratory experiments into school curricula. By providing investments in resources, training, and infrastructure to support lab-based learning, students will not only comprehend scientific concepts but apply them in meaningful ways. A lot depends on our serious commitment to the fact that students are given tools and experiences needed for success in the very field of STEM and further advancement of society.

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