THE DEVELOPMENT AND EVALUATION OF STEM 5E MODEL MODULE IN ENHANCING SCIENTIFIC LITERACY AND 21ST-CENTURY SKILLS AMONG NINTH-GRADE STUDENTS IN DOHA, QATAR

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by

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To the tent of tenderness and the cloud of place, to the one who holds me in her hands in continuous prayers to the sky, to the most beautiful thing in existence... my beloved mother.

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To the adornment and joy of this worldly life... my dear children.

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LIST OF ABBREVIATIONS

ATCEE	Achievement Test on Conversion of Electrical Energy
BSCS	Biological Science Curriculum Study
CTM	Conventional Teaching Method
EFNE	Education for a New Era
ISD	Instructional System Design
NGSS	Next Generation Science Standards
OECD	Organization for Economic Cooperation and Development
P21	Partnership for 21st-century Skills Learning
PBL	Problem-Based Learning
PISA	Programme for International Student Assessment
PjbL-STEM	Project-Based Learning STEM
PLTL	Peer-Led Team Learning
SPST	Scientific Process Skills Test
STEM	Science, Technology, Engineering, And Mathematics
STEM-5E	STEM-Based 5E Model
TBL	Thinking-Based Learning
TIMSS	Trend in International Mathematics and Science Analysis

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PEMBANGUNAN DAN PENILAIAN MODUL STEM 5E DALAM MENINGKATKAN LITERASI SAINTIFIK DAN KEMAHIRAN ABAD KE-21 DALAM KALANGAN MURID GRED SEMBILAN DI DOHA, QATAR

ABSTRAK

Kajian ini menyiasat tahap literasi saintifik dan kemahiran abad ke-21 murid gred sembilan yang rendah di Qatar, menunjukkan ketidakberkesanan kaedah pengajaran semasa. Bagi menangani isu ini, penyelidik membangunkan modul STEM-5E dan menilai keberkesanannya dalam meningkatkan literasi saintifik dan kemahiran abad ke-21 murid, dengan memberi tumpuan kepada topik Gelombang. Modul STEM-5E ini direka secara sistematik menggunakan model instruksional ADDIE, yang merangkumi fasa analisis, reka bentuk, pembangunan, pelaksanaan, dan penilaian. Modul ini telah disahkan oleh pakar dan diuji melalui kajian rintis yang melibatkan 30 murid. Literasi saintifik dinilai menggunakan ujian yang dibina berdasarkan Kerangka Literasi Saintifik PISA 2018, manakala kemahiran abad ke-21 diukur menggunakan ujian yang diadaptasi daripada Elbaz (2013) yang disesuaikan dengan kurikulum Qatar. Kedua-dua instrumen ini juga disahkan oleh pakar dan diuji dalam kajian rintis yang sama, menunjukkan kebolehpercayaan yang tinggi (Cronbach's alpha > 0.93) serta indeks kesukaran dan diskriminasi yang sesuai. Bagi menilai keberkesanan modul STEM-5E, kajian kuasi-eksperimen telah dijalankan selama lapan minggu dengan 120 murid dari dua sekolah awam peringkat persediaan. Para peserta dibahagikan kepada kumpulan eksperimen (62 murid), yang diajar menggunakan modul STEM-5E, dan kumpulan kawalan (58 murid), yang diajar menggunakan kaedah konvensional. Analisis statistik terhadap keputusan ujian pasca, termasuk ujian-T, ANCOVA sehala, dan MANCOVA sehala menunjukkan bahawa modul STEM-5E secara signifikan meningkatkan literasi saintifik, termasuk subkemahiran

seperti menerangkan fenomena, merancang penyiasatan, dan mentafsir data, serta meningkatkan kemahiran abad ke-21 seperti komunikasi, pemikiran kritis, kolaborasi, dan kreativiti. Secara keseluruhannya, modul STEM-5E terbukti lebih berkesan daripada pengajaran konvensional dalam meningkatkan literasi saintifik dan kemahiran abad ke-21, menunjukkan potensinya dalam memajukan pendidikan sains.5E lebih unggul dalam pasca-ujian bagi setiap subkemahiran abad ke-21.

THE DEVELOPMENT AND EVALUATION OF STEM 5E MODEL MODULE IN ENHANCING SCIENTIFIC LITERACY AND 21ST-CENTURY SKILLS AMONG NINTH-GRADE STUDENTS IN DOHA, QATAR

ABSTRACT

This study investigates the low scientific literacy and 21st-century skills of ninth-grade students in Qatar, highlighting the ineffectiveness of current teaching methods. To address this, the researcher develops the STEM-5E module and evaluates its effectiveness in enhancing students' scientific literacy and 21st-century skills, focusing on the Waves unit. The STEM-5E module, systematically designed using the ADDIE instructional model, which includes analysis, design, development, implementation, and evaluation phases, was validated by experts and tested in a pilot study with 30 students. Scientific literacy was assessed using a test developed based on the PISA 2018 Scientific Literacy Framework, while 21st-century skills were measured using a test adapted from Elbaz (2013) to align with Qatar's curriculum. Both instruments were also validated by experts and then tested in the same pilot study, showing high reliability (Cronbach's alpha > 0.93) and appropriate difficulty and discrimination indices. To evaluate the effectiveness of the STEM-5E module, a quasi-experimental study was conducted over eight weeks with 120 students from two preparatory public schools. The participants were divided into an experimental group (62 students), taught using the STEM-5E module, and a control group (58 students), taught using conventional methods. Statistical analyses of the post-test results, including T-test, one-way ANCOVA, and one-way MANCOVA revealed that the STEM-5E module significantly enhanced scientific literacy, including subskills like explaining phenomena, designing inquiries, and interpreting data, and improved 21st-century skills, such as communication, critical thinking, collaboration, and creativity. Overall, the STEM-5E module proved more effective than conventional teaching in fostering scientific literacy and 21st-century skills, highlighting its potential for advancing science education.

CHAPTER 1

INTRODUCTION

1.1 Introduction

The decision-makers, politicians, Stakeholders, and a broad spectrum of society demand educational systems that provide students with skills and competencies that allow them to contribute successfully to their society in accordance with 21st-century demands and to be ready for the challenges and Complications they will face (Katerina Ananiadou & Claro, 2009; Moore, 2016).

The integrated approach of Science, Technology, Engineering, And Mathematics (STEM) is one of the most important initiatives in education reform to equip individuals with the skills of the 21st-century. which is based on the idea of integrating the learning of the four disciplines into student-centered learning, problem-solving and scientific activities (Ganem, 2015; Manosuttirit, 2019; Saraç, 2018; Sarican & Akgunduz, 2018).

The idea that gaining scientific literacy would give students the knowledge and abilities they need to become responsible, scientifically literate citizens with the capacity for critical thinking, the construction of scientific arguments, and problem-solving abilities has led to an increasing emphasis on scientific literacy as the main goal of science education (Bybee, 1997; National Academies of Sciences, Engineering, 2016; Rennie et al., 2017).

Among the most important approaches for teaching science through scientific inquiry is the 5E model. (Bybee et al., 2006; NRC, 2010). The 5E is an instructional model established by the Biological Science Curriculum Study (BSCS) team in the late 1980s and is based on a constructive learning approach (Bybee et al., 2006). The phases of the 5E instructional model include engagement, exploration, explanation, elaboration, and evaluation. Each phase serves a distinct purpose, assisting the teacher in providing consistent learning and helping the learners develop a deeper understanding of science and technology knowledge, attitudes, and skills (Bybee et al., 2006; Bybee, 2009; Bybee & Landes, 1990).

Since 2003, Qatar has been taking part in International student assessment systems such as the Programme for International Student Assessment (PISA) and the Trend in International Mathematics and Science Analysis (TIMSS), which are widely mentioned by politicians and educators as indicators of the effectiveness or ineffectiveness of their school programs and teaching practices (Abou-El-Kheir, 2017; Qureshi et al., 2016).

Although the results were encouraging and showed an improvement in the level of students in Qatar, the results also imply that Qatar students' scientific literacy levels are still below expectations. As a result, an education reform program in Qatar is urgently needed to ensure the creation of citizens with 21st-century skills and to achieve Qatar National Vision 2030, which will lead to sustainable growth in all fields. (Abou-El-Kheir, 2017).

1.2 Background of the Study

1.2.1 STEM

STEM was first introduced in the United States in the 1990s, when studies suggested students should be encouraged to study in these disciplines and that new science and math teaching techniques should be investigated (Bybee, 2013; Sanders, 2009). The National Science Foundation (NSF) established the foundation of the STEM education approach. Then, the approach spread throughout the United States of America and was adopted by many countries such as England, Korea, Australia, Singapore, and others.

Literacy in STEM disciplines is critical for each citizen's personal quality of life and the nation's competitiveness in the international economy. In order to do this, the UNESCO General Assembly Incheon Declaration for Education 2030 advocated strengthening STEM education as a key approach for achieving the 17 Sustainable Development Goals (SDGs) (UNESCO, 2015).

Integrated STEM education is based on the constructivism theory and is considered a recent development from the initiative to integrate the general curricula of the constructivist movement (Murphy et al., 2020; Richardson, 2016). STEM education focuses on real-world issues and everyday life. It requires high-quality curricula and distinct learning strategies focused on scientific inquiry (Bybee, 2013b; Kelley & Knowles, 2016; Kennedy & Odell, 2014; NRC, 2011a; Sanders, 2009).

Numerous educators emphasized the value of STEM education in developing highly skilled scientists, engineers, and technicians, inspiring students to pursue STEM careers, and equipping pupils for life in the 21st-century. Additionally, a number of studies have demonstrated the effectiveness of STEM in assisting students in meeting cognitive and skill objectives, enhancing students' accomplishment (Becker & Park, 2011; Boyster, 2018; Bybee, 2013b; NRC, 2014), increasing their knowledge of the content of science, mathematics technology, and engineering (Bishop, 2015; Sanders, 2009), The improvement of critical thinking, problem-solving, and scientific research abilities (Altan et al., 2018; Baran et al., 2016; Stohlmann et al., 2012), and technological design (Abdlfattah, 2016).

Many educators argue that STEM education is a science education reform initiative, mainly because the US National Science Foundation (NSF) initially proposed the acronym "STEM" in the 1990s. (Ring, 2017; Wei & Chen, 2020; Yager, 2015). In addition, it is not new for technology and engineering to be introduced into science education (Bybee, 2013b). Also, Standards for Technology and Engineering are available in science for All Americans (AAAS, 1989), Benchmarks for Science Literacy (AAAS, 1993), and the National Science Education Standards (NRC, 1996). Additionally, the Next Generation Science Standards (NGSS) in the United States emphasize the intentional integration of STEM through fostering deeper links between STEM subjects (NRC, 2013; Portz, 2015).

According to researchers, if STEM education is used for learning physics topics like waves, students will learn scientific skills in a well-designed environment. The STEM education classes enable students to remember physics topics in settings that they are familiar with and that can develop connections between different disciplines and the development of solid competencies (Tupsai et al., 2019).

The mid-2000s saw a global push for STEM education, now recognized as essential for economic expansion and sustainable development (Gonzalez & Kuenzi, 2012). According to the UNESCO Incheon Declaration, "Education 2030", quality STEM education is required for sustainable development and technological innovation (UNESCO, 2015). European Union, the United Kingdom, Canada, and Australia have also promoted the growth of STEM through educational institutions, initiatives for new teachers, and collaborations with businesses (Bubnick et al., 2016; Council of Canadian Academics, 2015; HM Treasury, 2011; Taylor, 2016) Several programs to improve STEM education have been established in Asia by nations including China, Japan, and Korea (Gao, 2013; Jon & Chung, 2014; Suwarma, 2014). Malaysia has a three-phase strategy for the growth of STEM education (MoE Malaysia, 2016).

In Qatar, Qatar University, private universities, and other scientific and cultural institutes, spearheaded the implementation of several STEM programs and activities throughout the second decade of the 21st-century (Qatar University, 2018; Texas A&M University at Qatar, 2018). In addition, several private schools have added the STEM education program to their programs (Cherian, 2019; Sherborne Qatar, 2021).

In 2018, the Ministry of Education and Higher Education of the State of Qatar unveiled the new "Science Curriculum Standards for the State of Qatar". The new standards included the integration of science with both mathematics and technology (MoEHE-Qatar, 2020). In 2021, the Ministry of Education and Higher Education issued the new science curricula for the ninth grade. These curricula included a project for each academic unit. This project integrates science, technology, engineering and mathematics (MoEHE-Qatar, 2021a).

Despite the Qatari government's efforts and investments to embrace STEM integration in public schools over the last two decades, the outcomes have been unsatisfactory (Treagust et al., 2020). Although there are attempts to integrate science with mathematics and technology in the new science curriculum, this is not enough to be integrated into the STEM education curriculum (MoEHE-Qatar, 2023a).

1.2.2 5E Instructional Model

The 5E model of instruction has been extensively utilized in the Biological Science Curriculum Study (BSCS) to foster a more profound comprehension of scientific and technical information, attitudes, and abilities. The BSCS 5E, often known as the 5E instructional model, is regarded as an inquiry-based learning aproachapproach that promotes constructivist pedagogy. The five phases of this model are "engagement, exploration, explanation, elaboration, and evaluation". Each phase has a certain function (Bybee et al., 2006; Ihejiamaizu et al., 2018; Texley & Ruud, 2018).

The 5E model's five phases aim to assist 5E conceptual transformation, offer consistency to different instructional strategies, establish links across instructional activities, and assist science teachers in making choices about student interactions. It offers a well-considered set of lessons that center learning on the needs of the students. It motivates all students to do research, develop a basic comprehension of scientific ideas, and apply those ideas to technological problems or occurrences (Bybee et al., 2006).

Through the use of this 5E model—which incorporates self-reflection and interaction with others and the environment—students redefine, reorganize, elaborate, and update their original ideas. Students examine objects and events through the lens of their current conceptual understanding, internalizing the meanings they are given. The approach can be applied or integrated at different levels by science instructors and curriculum designers. The 5E approach can be used to organize yearly programs, units of study, or daily schedules. (Bybee, 1997).

The 5E instructional model is widely used in science learning (Bybee et al., 2006; Morgan et al., 2013). Because the 5E model improves cognitive process skills, achievements, attitudes, higher-order thinking, problem-solving, and incentives. (Bybee, 2009). In addition, It is helpful to use it in STEM classes (Bybee, 2019) because the 5E instructional model is inquiry-based learning focused on real-world issues (Rodriguez et al., 2019) and valuable for 21st-century skills learning (Bybee, 2009; Chitman-Brooker & Kopp, 2013; Rodriguez et al., 2019).

The 5E model encourages the growth of scientific literacy (Hall, 2021); by adhering to the 5E model, teachers may make sure that students investigate the subject, make sense of what they're thinking, and learn more about it (Bybee et al., 2006). The 5E model also highlights the need for students to evaluate their understanding and use of scientific concepts, because it encourages students to assess the validity of their information and reflect on their learning, this evaluation process is essential for developing scientific literacy (Bybee, 2009; NSTA, 2018)

One of the preferred learning models used by educators in STEM education is the 5E model (Dass, 2015). Bybee, the team leader who created the 5E instructional model, argues that the model is ideal for STEM education and 21st-century skills (Bybee, 2015). The 5E model with the STEM approach conforms because it provides students with opportunities to develop 21st-century skills (Bybee, 2019). Additionally, learning across disciplines is encouraged by the five phases of 5E and the STEM approach (Sugiarti et al., 2018).

When STEM and the 5E model are interconnected, students may gain from a comprehensive, integrated learning experience. By combining the finest components of the 5E and STEM approaches, educators may create a comprehensive learning program. As students work through challenges from the real world, 5E exercises may spark their interest and curiosity and aid in developing scientific reasoning abilities. Students are encouraged to apply their knowledge to new circumstances and think critically using inquiry-based learning (Bybee, 2019; Kaniawati et al., 2017).

1.2.3 STEM-based 5E module (STEM-5E)

STEM-based 5E model module is a module that uses the 5E Instructional model in learning science in an integrated STEM classroom. It is regarded as a STEM-based module, given that STEM disciplines are included in the 5E instructional model phases. Every phase of the 5E Instructional model should have some STEM disciplines. Some of the 5E instructional model phases described that it contains some disciplines more than others. For instance, the engineering discipline is incorporated into the elaboration phase, as students are motivated to build and construct, utilizing the technical tools of the scientific and mathematics information they have just learned (Ong et al., 2020).

According to Bybee (2009), the 5E model is an inquiry-based model aligns with constructivist philosophy. student-centered learning strategy in which the instructor and the pupil take an active role in the educational process (Eroğlu & Bektaş, 2022). The 5E provides a pedagogical approach in which instruction is structured so that the goal and relevance of lesson content are established early on in real-life contexts, and students actively participate in the educational process (Dass, 2015). On the other hand, STEM education is based on constructivism's concepts (Sanders, 2009), emphasizes student-~~centred~~centered learning (Falloon et al., 2020a), it attempts to engage students in resolving complex situations that mirror problems in the real world. (Roberts, 2012; Sahin, 2013). All this indicates that the 5E instructional model suits integrated STEM education.

The 5E Model can be said to be very appropriate in STEM education as it is also effective in enabling students to learn and employ the scientific, technological, engineering, and mathematical concepts around by way of investigation and activities embedded with a practical approach (Bybee, 2019; Dass, 2015).

The first phase of the 5E model, Engagement, involves attracting students' attention, sometimes through a question, a real problem or a situation connected with the content of STEM programs. When focusing on STEM projects, engagement could be in the form of a problem presentation, a fantastic demonstration of a skill, or a display of a practical example. For instance, teachers can provide students with the ICT problem or the tool illustrating the problem such as programming a game or demonstrating the use of an app that provides an effective solution. In STEM education, there is often an interesting question, riddle or situation from the real life which evokes interest to use mathematics.(Ohn-Sabatello, 2020; Poonja et al., 2023; Shofiyah et al., 2023).

The second phase of the 5E model, Exploration phase, involves students' interaction with physical materials and conducting experiments which brings the practical aspect of learning, which in this case is the core of STEM. Some students are able to carry out experiments, develop models or perform simulations among others to comprehend STEM concepts even before they are taught. This phase of exploration is crucial in STEM because it enables learners to watch, think, and try things in an environment that is safe and designed for innovation and invention. Students are engaged with more tangible technologies, including new software, or hardware, or both, as they try to understand different technologies. It could be that students will experiment with one or more materials, a prototype as well as design, engaging in trial and error, and learning through failure (A. Gilbert & Wade, 2014; Ohn-Sabatello, 2020).

During the Explanation phase, students start to interpret and comprehend what it is that they have investigated. The STEM educators either have discussions or teach directly to help the students understand complex ideas or concepts, the scientific theories or the mathematics that was relevant when the students were doing the exploration. There are some ways in which teachers can help students clarify concepts including showing how certain technologies operate or how such technologies are used in society. As the projects go on, students make inappropriate choices in design, learn proper suggestions for their design, and find out how the materials, or mechanics used in their prototypes/functions (Chen et al., 2022; Gilbert & Wade, 2014; Ohn-Sabatello, 2020).

In the Elaboration phase, educational psychologists posit that Children integrate the newly acquired knowledge and apply it to new contexts, with many of them also deepening their knowledge as they take on new challenges or revisit their original project which is also a problem-solving exercise. Such phase is particularly critical in STEM education because it includes cognitive tasks such as critical analysis, creative problem-solving, and design which are key requirements in these professions. Among the tasks that students might do include working out challenges that are based on design/making engineering concepts for example applying mathematics to obtain desired output, or controlling variables in science experimentation (Chen et al., 2022; Gilbert & Wade, 2014).

During the Evaluation phase, students make sense of what they have learnt, show what they know, and get feedback. In STEM education, evaluation can take the form of additional assessments or tests that are either in milestones such as midterm or final, or embedded in a STEM project, lab report, or practical demonstration. This phase imitates real engineering processes were evaluating how functional, safe, and efficient a system is, is very important. Also, it includes problem-solving activities that may cover discussions or simulations aimed at ascertaining students' understanding of mathematical concepts and the strategies for solving them (S. Chen et al., 2022; A. Gilbert & Wade, 2014).

Because science education is crucial to the development of the nation, Qatar has made significant efforts to improve it. In this way, it has built new schools that match the most modern international standards and provided students with a dynamic learning environment that encourages interactive learning. Developing the curriculum for all academic levels in an integrated manner, to form a comprehensive set of scientific concepts that correspond to the ages of students and which contribute to demonstrating their progress clearly. (Malkawi, 2022; MoEHE-Qatar, 2020, 2023a).

PISA's scientific literacy framework is considered one of the most essential and famous scientific literacy frameworks. It is a component of the "Programme for International Student Assessment (PISA)", which assesses how well students at the 15-year-old age who are almost finished with their mandatory education have learned the knowledge and abilities needed to participate actively in modern society. The assessment examines how well students can apply what they have learned in novel situations, both inside and outside of the classroom, and extrapolate from what they have learned. It also looks at whether or not they can reproduce knowledge (OECD, 2017, 2019b).

According to OECD (2019b), the PISA 2018 scientific literacy framework considers a scientifically literate citizen is a person equipped to engage in a rational discussion about science and technology. This requires that he possess the following competencies: "Explaining phenomena scientifically", "Evaluating and planning scientific inquiry", and “Interpreting data and evidence Scientifically”.

Waves topic is one of the physics topics involving principles that must be mastered to establish scientific literacy. The topic of waves also includes several indicators for the PISA scientific literacy framework competencies, such as describing changes in wave phenomena brought on by wave refraction, reflection, interference, dispersion, diffraction, resonance, and polarization; using realistic examples; defining the distinction between mechanical and electromagnetic waves; and more. Real-world examples can be used to explain the distinctions between longitudinal and transverse waves, as well as standing waves and stationary waves, and applications of reflecting sound waves to gauge water depth (Sahyar et al., 2020).

The topic of waves was selected for this study for several reasons. First, waves are a fundamental concept in physics, and scientific literacy in the context of waves means having a basic understanding of the behavior and properties of waves, such as their wavelength, amplitude, frequency, and speed. (Banks & Barlex, 2014; Bugingo et al., 2022; Common Core State Standards Initiative, 2010; Eke, 2015). Second, studying waves might help students master 21st-century skills: "creativity, communication, collaboration, and critical thinking." In today's society, these skills are considered essential for success, especially in the workplace (Partnership for 21st

Century Skills, 2019). Additionally, because of its interdisciplinary nature and the fact that it encompasses various concepts that can be taught through inquiry-based learning and hands-on activities, the topic of waves is very appropriate for teaching using the 5E model in STEM classrooms setting (Awad, 2021; Bybee, 2014). Furthermore, knowing about waves is a challenge for ninth-grade student in Qatar (MoEHE-Qatar, 2023c).

The aim of scientific literacy, science education, and the waves topic is to develop a student's capacity to grasp scientific concepts, critically examine scientific challenges, and make sound judgments in their own life and in society as a whole. Scientific literacy turns students into scholars since they are required to acquire the essential competencies to scrutinize, comprehend, and articulate scientific material (Dragoş & Mih, 2015; Sulistiowati et al., 2019).

Acquiring scientific literacy is crucial since everyone needs much information, expertise, and knowledge to make wise decisions, handle challenges as they emerge, and find solutions to everyday issues. (Bahriah & Irwandi, 2020). However, students' problem-solving skills are improved by the STEM education approach, which also improves their independence, creativity, logical thinking, and technological literacy. (Bybee, 2013b; Sanders, 2009; Stohlmann et al., 2012).

A well-designed educational module can help students become scientifically literate, allowing for intelligent engagement with socio-scientific issues, informed decisions, and good societal influence (Kolstø, 2001). Students are introduced to real-world, socio-scientific problems that incorporate physics through an excellent scientific literacy curriculum. Students are taught to balance the advantages against any potential disadvantages for their health or the environment in order to encourage responsible conduct and informed opinions (Sengul, 2019).

Scientific literacy is the aim of physics education, which serves as the basis for science education (Holbrook & Rannikmae, 2009; Pamungkas et al., 2018). This is because the primary objective of science education is to provide students the chance to decide on socioscientific problems that impact their lives (OECD, 2007). Additionally, understanding the concepts with scientific skills was necessary for studying physics, as it applied the concepts or facts learned in class to real-world everyday activities. Hence, learning physics should improve students' scientific literacy (Parno et al., 2020).

Scientific literacy means understanding fundamental ideas of waves and their applications in real-life, including technology, sound, and light. Students who are "literate" in waves are able to handle problems in the real world, critically evaluate information, and make well-informed judgements about matters pertaining to waves and similar phenomena. This involves having the skills to analyze scientific data, evaluate the effects of wave technology, and participate in scientific discussions on waves in society (Ariska & Rosana, 2020; Kalsum et al., 2023; Sahyar et al., 2020).

The term "achievement in waves" describes how well students do quantifiably on examinations or assessments that particularly address the subject of waves. This entails proving an understanding of wave characteristics, doing calculations, and resolving problems that are specifically associated with wave phenomena. Here, the emphasis is on helping students meet certain academic goals, such doing well on exams, accurately completing lab tasks, and comprehending theoretical topics as needed by the curriculum (Bradford, 2015; Nkwo et al., 2021; Steinmayr et al., 2014).

Scientific literacy and achievement in waves ~~are~~are related ideas. Students with higher scientific literacy in waves fare better in performance in wave assessments and problems. This is so because scientific literacy offers a basis for grasp of wave ideas and use of these in problem solving (Hodson, 2008). Furthermore, achievement in waves can also help positively develop scientific literacy in waves. Wave concepts when taught and used by students enhance the understanding of the science principles and the related phenomenon (Linn & Gronlund, 2021)

However, scientific literacy and achievement in waves could be considered as two correlated but different things; Scientific literacy related to waves deals with the skills with which students understand the scientific facts regarding waves, while achievement related to waves has to do with the extent of success of the students in mastering the wave concepts. Scientific literacy of a few waves has a larger focus on concepts and phenomena of waves while on the other hand achievement in waves is focused on only a few concepts and skills of waves (Ariska & Rosana, 2020; Kalsum et al., 2023; Krisdiana et al., 2018).

Qatar has instituted a series of educational changes, including science education, with the aim of raising student scientific literacy and incorporating scientific inquiry techniques and methods into science disciplines (Calder et al., 2020; Nasser et al., 2014), to achieve qualitative learning and learning outcomes of high quality through a more precise focus on the competencies that all students require, to be prepared to react successfully and respond to the opportunities and challenges posed by the 21st-century (Abou-El-Kheir, 2017; MoEHE-Qatar, 2011, 2020; Qureshi et al., 2016).

Despite all the efforts undertaken in Qatar, the degree of scientific literacy in Qatar still needs to improve. The PISA 2018 scientific literacy test results reveal that 15-year-old students in Qatar perform poorly; their average score was 419, compared to 489 for all participating nations (OECD, 2019a). Results from the PISA 2018 scientific literacy test show that only 2% of Qatar students demonstrated outstanding performance in science (participating countries average: 7%) (OECD, 2019b).

1.2.4 Twenty-First Century Skills Among Students in Qatar

21st-century skills refer to a global movement to rethink educational goals and learning approaches in response to the question: "What do students need to learn for life in our time?" In a world transforming from an industrial era to a technological and innovation-driven one (Carnoy, 1999; National Educational Association, 2011; Trilling & Fadel, 2009).

A nation must create an educational system where students learn about science, mathematics, engineering, and technology and produce products using critical skills to participate in the 21st-century global economic system (Akgunduz, 2016). STEM education aims to enhance thinking, teamwork, reasoning, investigation, and 21st-century abilities that learners may use in every facet of their life. These skills, known as the "4Cs," have become critical to success in the 21st-century (Akgunduz, 2016; Milaturrahmah et al., 2017).

Many frameworks have been developed with international organizations, governments, and consulting businesses to enhance citizens' grasp of 21st-century skills. One of these frameworks effectively clarified the key idea of 21st-century skills. It is called “Partnership for 21st-century Skills Learning (P21)”, Founded with the collaboration of the US administration and many business sector organizations (e.g., National Education Association, Apple, Microsoft, Cisco, Dell, , and others) to put 21st-century skills at the center of K-12 education. (Partnership for 21st-century Learning, 2019a; Partnership for 21st-century Skills, 2008).

Even though different 21st-century skills frameworks presented different classifications of 21st-century skills, the most common 21st-century skills and competencies shown in these frameworks and most connected in multiple aspects of life are referred to as the "4Cs": communication, collaboration, creativity, and critical thinking (Ontario Public Service, 2016). In 2006, the director-general of UNESCO addressed a conference titled "Building Creative Competencies for the 21st-century " and stated that the 4Cs skills should be used to address global challenges (Trilling & Fadel, 2009). The 4Cs skills and P21 framework will be used in this research as a 21st-century skills framework.

In order to provide students with 21st-century skills, physics education in schools is essential. After learning physics, students should be able to perform inquiries using scientific methods, solve problems, work cooperatively, and communicate research findings through writing, presentations, and other means. These competencies include analyzing the principles, physical events, and mathematical reasons for these events. They should also be able to apply their knowledge of physics in everyday life. As a result, studying physics is an integrated discipline that promotes the acquisition of 21st-century skills, and this issue has been extensively researched (Foote, 2020; Hidayatullah et al., 2021; Novitra et al., 2021).

Many educational changes have been implemented in Qatar to achieve Qatar's National Vision 2030, which aims to produce graduates who will significantly contribute to the country's scientific and technological economies (Qureshi et al., 2016). Moreover, this requires acquiring 21st-century skills (General Secretariat For Development Planning, 2008; Said, 2016). Recently, to meet the education goals of Qatar National Vision 2030, the new Qatari preparatory school curriculum focuses on 21st-century skills (MoEHE-Qatar, 2023a, 2023c).

Numerous research studies revealed that the Qatari school curriculum, learning activities, and evaluation techniques lacked 21st-century skills (Al-Kuwari et al., 2021). Additionally, there is a disconnect between the Ministry of Education's strategy and the Qatar National Vision 2030's environmental issues, sustainable development goals, and learning outcomes (Al-Kuwari et al., 2021), and inadequate critical reasoning abilities (Sharfeldin et al., 2018). All this data suggests that Qatar's educational system needs fresh transformation to meet the goals of Qatar National Vision 2030 since both the degree of scientific literacy and the level of 21st-century skills are poor.

1.2.5 Teaching Topic of Waves in Qatar

Waves are one of the most essential physics topics since waves are everywhere in human life (Di Renzone et al., 2014) and have numerous applications in daily life; in addition, wave concepts are essential in all communication systems (Hess, 2013). At the same time, several studies show that students face difficulties understanding waves concepts (Awad, 2020; Di Renzone et al., 2014; Kanyesigye et al., 2022; Wittmann et al., 2003). Moreover, waves concepts have many misconceptions (Awad

& Barak, 2018; Chang et al., 2007; Eshach & Schwartz, 2006; Pejuan et al., 2012; Sözen & Bolat, 2011).

Researchers also reported that learning waves concepts in STEM education enables students to understand the technical and physical components of topics like Waves, sound, and communication (Awad & Barak, 2018). It supports students in cultivating higher order thinking abilities so that they may become creative, and problem solvers, as well as develop conceptual understanding, and systems thinking (Awad, 2021; Nurhayati et al., 2022). This may be because the fact that the subjects of sound, waves, and communication include a wide range of technological, engineering, and mathematical concepts and applications (Ganiev et al., 2015).

Qatar Public School curriculum for the ~~ninth-grade~~ninth grade introduces the topic of waves in unit 10. This unit discusses transverse waves and longitudinal waves, how we change the frequency and amplitude of sounds. What frequencies can a person hear? How does echo occur? And the uses of the different types of electromagnetic waves (MoEHE-Qatar, 2023a). Waves unit is supposed to be taught using active learning strategies and scientific inquiry (MoEHE-Qatar, 2023c).

Although no studies (according to the limits of the researcher's knowledge) about teaching and learning of the topic of waves in Qatar state, or about students' understanding the topic of waves in Qatar stat, the follow-up to the teaching process does not somehow indicate successful practices in teaching the subject of waves, furthermore, Qatari students' performance on international examinations suggests that they have a weak understanding of scientific literacy. In the PISA test, 2% of students in Qatar scored in the top quartile in science, while 48% scored in the bottom quartile (OECD, 2019b).

1.3 Problem Statement

Qatar National Vision 2030 strives to create a contemporary, premier learning system that offers students an education on par with other countries. The system will provide individuals with great instruction and chances to reach their full potential, equipping them for success in a changing environment with more advanced technological needs. In addition, the system will promote critical and analytical thinking, and creativity. It will encourage social togetherness, appreciation for history of Qatari society, as well as constructive international collaboration (General Secretariat For Development Planning, 2008).

Notwithstanding Qatar's initiatives to enhance educational methods and switch to student-centered learning approaches, there is criticism over the continuous use of conventional methods of instruction and evaluation (Treagust et al., 2020). According to Said et al. (2018), the scientific education methods used in Qatar cannot be considered of a high caliber in terms of accuracy, consistency, or standard. Changes in Qatar's methodologies for instruction are necessary, as evidenced by the country's performance on international assessments (Qureshi et al., 2016). Additionally, the researcher - throughout his ten years of experience in teaching science at a public preparatory school in Qatar - observed the lack of clarity in student-centered learning and the inclination to use traditional techniques of scientific teaching.

The results of the PISA 2018 scientific literacy test show that Qatar students at the age of 15 do poorly in the scientific literacy test; the average score of Qatar students at the age of 15 in the scientific literacy PISA 2018 test was 419, compared to 489, the average for all participating countries and was ranked 58th out of 78 countries participated in the PISA 2018 test (OECD, 2019c).

PISA 2018 test results reveal that 52% of Qatar students achieved Level 2 or above in science (participating countries' average: 78%). These students should be able to recognize the proper explanation for common scientific occurrences and be able to utilize that knowledge to determine if a conclusion is proper based on the facts supplied in essential scenarios. Moreover, only 2% of Qatar students were outstanding performers in science, with Level 5 or 6 proficiency (all-Participating countries' average: 7%). These students can use their scientific knowledge and comprehension in original and independent ways in a variety of contexts, even some foreign to them (OECD, 2019b).

Regarding the performance of Qatar students on each subscale of scientific literacy competencies, there is no data published in the PISA 2018 test because the focus was not on the science test. However, in PISA 2015 test the focus was on science, so there is data on the performance of Qatar's students on each subscale of science competencies (OECD, 2016, 2019c).

In the PISA 2015 test, Qatar's students 15-year-old had an average scientific literacy score of 418, almost the same as their performance in the 2018 test, which was 419 (OECD, 2016, 2019c). In "Explain Phenomena Scientifically" competency, the Qatar student average in PISA 2015test was 414. while all-Participating countries' average was 493. This indicates poor performance in "Explain Phenomena Scientifically" competency (OECD, 2016).

In "evaluate and design scientific inquiry" competency, the Qatar student average in 2015 PISA test was 418. while all-Participating countries' average was 493. This indicates also poor performance in "Evaluate and design scientific inquiry" competency (OECD, 2016). And in "Interpret data and evidence scientifically" competency, the Qatar student average was 417. while all-Participating countries' average was 493. This indicates also poor performance in "Interpret data and evidence scientifically" competency (OECD, 2016).

In conclusion, scientific literacy scores among Qatari students continue to be low on a worldwide scale. Moreover, still below the ambitions that the state of Qatar aspires to. Qatar ranked 58 of the 79 participating countries in the PISA 2018 Scientific literacy test. According to educators, the results portend a terrible reality regarding the prospects for creating well-educated citizens accustomed to thinking critically, which would improve economies and strengthen civil society (Bolg, 2019; OECD, 2019a).

In addition, several studies indicated the lack of scientific literacy skills among Qatari students (Ari & Koç, 2022; Fadlelmula & Koc, 2016; Farah, 2017; Treagust et al., 2020), the use of traditional techniques for instruction and evaluation (Treagust et al., 2020), insufficient curriculum resources (Treagust et al., 2020), and the use of low-quality teaching methods when teaching science (Said et al., 2018).

In terms of 21st-century skills, there are no studies that directly measure the level of 21st-century skills among students in the State of Qatar (according to the researcher's knowledge limits), but the level of some of these skills can be inferred through international tests such as the PISA test, which is an indicator that measures many 21st-century skills; PISA tests measure how well students have learned important concepts and skills that are required for full involvement in economic and social life (NRC, 2012). PISA tests look at how effectively Students are able to draw conclusions from their knowledge and apply it in novel contexts, inside as well as outside of the classroom (OECD, 2020).

PISA 2018 results unearth that in science, reading, and mathematics, Qatar students performed inferiorly to the average of all participating countries. PISA 2018 results also reveal that only around 3% of Qatar students were outstanding scorers in reading (all-participating countries’ average: 9%). 3% of Qatar students were outstanding scorers in mathematics (all-Participating countries' average: 11%). 2% of Qatar students were outstanding scorers in science (all-Participating countries’ average: 7%) (OECD, 2019c). These results indicate a low level of 21st-century skills.

In addition, a number of studies indicated the lack of 21st-century skills in school curricula, learning activities and assessment methods in Qatar (Al-Kuwari et al., 2021). And the mismatch between the current learning outcomes, The goals of sustainable development and the environmental factors identified in the Qatar National Vision 2030 and the strategy of Qatari Ministry of Education (Al-Kuwari, Al-Fagih, et al., 2021). And poor critical thinking skills (Sharfeldin et al., 2018). The Qatari labor-market reports also revealed a glaring lack of acquired skill level (Ali et al., 2021), a substantial skills gap in the market, and employers' dissatisfaction with business graduates' performance and skill set (Alshare & Sewailem, 2018).

Analyzing different levels of schooling, scientific literacy and 21st-century skills in Qatar science textbooks differ to some extent. A study done on the use of primary science textbooks in Qatar reveal that 21st century themes’ average availability rate was moderate at 42.8%1. Health literacy and Environmental literacy were the most observed. (Mohammed & Malkawi, 2023).

In addition, the content analysis of the ninth-grade science textbook by the researcher (in chapter two) shows that the competencies of scientific literacy are included, but not comprehensively. While the explanation of scientific phenomena is well covered, the evaluation and design of scientific inquiry, and the interpretation of data and evidence require further development. More detail and depth are needed in the analysis of results, along with connections to broader scientific concepts. The content analysis also shows that the textbook focuses on developing 21st century skills (critical thinking, communication, collaboration, and creativity) through interactive activities and practical applications, and promotes digital literacy using simple digital tools.

The researcher’s experience in teaching for 10 years in the State of Qatar confirms that although the science curricula contain scientific literacy competencies and twenty-first century skills, this is not reflected in their development among students due to the ineffectiveness of teaching strategies and methods.

This study is unique in that it is the first study to measure the level of 21st-century skills among ninth graders in Qatar's public schools. It also measures the level of the main sub-skills (4Cs), which are: communication, critical thinking, creativity and innovation, and collaboration.

Evidence indicates that the current teaching approaches used in ninth-grade Qatari public schools are not effective enough to help students improve their scientific literacy and 21st-century skills. So, science education in Qatar needs new teaching methods to develop scientific literacy and 21st-century skills.

Since the integrated STEM education approach has the potential to develop scientific skills in a very well environment, enables students to learn physics in environments that they are familiar with, and can foster connections between various disciplines and the development of solid competencies (Tupsai et al., 2019), it can also improve students' thinking, teamwork, reasoning, investigation, and 21st-century skills