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A review of game-based learning in fuel cell education for secondary students

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ABSTRACT

The need for fuel cell education is now critical since fuel cell exposure can build future economies, human capital, and environmental consciousness, as fuel cell is the future green technology. This can be communicated through educational programs that guarantee the transfer of knowledge is relevant and transparent. This paper provides an overview of the need to prepare our students, who will be the next generation of potential fuel cell users and designers, for the impending widespread adoption and use of hydrogen fuel cell technology. To ensure that the learning process is interesting and inspiring, mobile games are demonstrating their promise as useful instruments for assisting fuel cell teaching. With the application of various game design elements, game-based learning has been demonstrated to boost cognitive growth, learning experiences, learning engagement, and motivation. As a result, research must continue to focus on the creation of fuel cell education modules for secondary students that use mobile games as learning tools. By integrating game-based learning into fuel cell education, we can inspire and empower the next generation of professionals to drive the transition towards sustainable energy future.

1. INTRODUCTION

Despite economic developments, industrialisation, and population growth, the demand to meet the world's energy demands is increasing. In 2018, Malaysia's industry sector utilised around 19 million tonnes of oil, accounting for nearly 30% of total final energy consumption, demonstrating Malaysia's considerable reliance on fossil fuel equivalent as its primary energy supplier (Li & Solaymani, 2021). However, the nation now needs to discover alternate energy sources due to the recent sharp fluctuations in the price of fossil fuels. Despite being the primary energy source meeting the world's present energy needs, fossil fuels are also rapidly running out of supply (Asadi et al., 2021).

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The majority of Malaysia's energy comes from fossil fuels, which significantly increase carbon emissions (Zakaria et al., 2021). The high fossil fuel usage in daily consumption especially in transportation causes the emission of pollutants which have increased serious negative effects on the environment (Al-Amin & Doberstein, 2019). In addition to their harmful impact on the environment, burning fossil fuels releases carbon dioxide into the atmosphere, which plays a significant role in the greenhouse effect and global warming (Azni et al., 2023). According to the Blueprint of Fuel Cell Industries in Malaysia, the hydrogen economy envisioned for Malaysia included hydrogen as the 'sixth fuel' to contribute to the required greenhouse gas emissions reduction that the country aspires as Malaysia has pledged in the National Policy to reduce 40% of carbon emission by 2030. Given the exceptional circumstances, hydrogen is likely the most promising fuel option locally because it is more environmentally friendly (Akademi Sains Malaysia, 2017).

The problem of the global warming crisis and the rise in energy demand in every nation are driving the rapid development of alternative energy, including new technologies for renewable energy. Fuel cells are one of the promising alternative energy received strong support and the demand kept increasing for years in several countries such as the United State of Amerika (USA), Japan, Korea, and the United Kingdom (UK) (Xu et al., 2017). Fuel cells, which are becoming more and more popular, have been identified as the most potential energy conversion technology for hydrogen, particularly for use in transportation (Fang et al., 2021).

Fuel cells have gained a lot of attention due to its ability to produce no greenhouse gas emissions. Hydrogen and oxygen from the air react chemically to produce energy for fuel cells (Sazali et al., 2020). The electrochemical cell in a fuel cell will produce electricity directly from hydrogen and oxygen which are available in the air (Hacker & Mitsushima, 2018). After solar energy, hydrogen has been shown to be one of the most practical and long-term renewable substitutes for fossil fuels due to its abundance on Earth. Fuel cells are electrochemical devices that use hydrogen as fuel to transform chemical energy into electrical energy. An effective, long-lasting, and ecologically safe method of converting energy is offered by fuel cell technology (Dicks & Rand, 2018).

Fuel cells have many significant advantages if compared with conventional batteries and internal combustion engines (Hacker & Mitsushima, 2018). A variety of fuel sources, including hydrogen, methanol, ethanol, and natural gas, can be utilised as fuel in fuel cell systems, making this one of them. More than 50% fuel energy conversion efficiency is possible, and to achieve the desired power output, the energy efficiency can be varied by adding numerous single cells. Furthermore, there will be no issues regarding noise in the system because it only consists of a few moving parts (Zakaria et al., 2021). Though it functions similarly to a regular battery in theory, a fuel cell doesn't run out of fuel or needs to be charged as long as fuel is available.

One of the difficulties in getting fuel cell technology into practice is the fact that hydrocarbon reformation processes generate 96% of the hydrogen produced worldwide. Fossil fuel is extracted, primarily from natural gas, and used in fuel cells to make hydrogen. Therefore, the only practical way to aid in the transition from a fossil fuel-based economy to a renewable-based, hydrogen-facilitated economy is to promote renewable-based hydrogen (Zakaria et al., 2023). The current situation calls for more research and development to reduce the high cost of fuel cell technologies Introduction of fuel cell awareness among industries and the public is a crucial step in promoting market demands, thus encouraging research and development of the technology (Hardman et al., 2017).

In Malaysia, various strategies have been formulated to initiate, improve, and foster the fuel cell industry. Among the strategies are focused on introducing fuel cell technology to the industry and the awareness about the use of fuel cell technology to the general public (Akademi Sains Malaysia, 2017). The blueprint of Fuel Cell industries in Malaysia outlines are still in progress but the steps to ensure acceptance of fuel cell technology as an alternative energy source in the country have been taken as a priority. There are various methods to convey knowledge about new technology to the public as campaigning, advertising,

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and education (Fang et al., 2021). However, among the various methods, educational programs can provide a meaningful transfer of knowledge and it is more transparent (Mora et al., 2020).

Fuel cell education faces challenges such as limited coverage in school curricula and a lack of engaging materials to explain complex concepts. Current teaching methods often fall short in offering hands-on learning experiences that help students apply theoretical knowledge to real-world fuel cell technology. The scope of this review includes examining the current state of fuel cell education, identifying gaps in learning resources, and assessing the potential for mobile games to enhance student understanding and engagement in this field. Mobile games can simulate real-world fuel cell scenarios, helping students better understand and engage with the subject. By enhancing both theoretical and practical learning, game-based education offers an innovative solution to prepare students for the growing clean energy sector.

Therefore, the objective of this paper is to express the interests and needs to introduce fuel cell education starting from lower education. This will discuss the importance of preparing our students, who will be the generation that uses and designs fuel cells in the future, for the broad adoption and impending use of hydrogen fuel cell technology. This paper will also review the various methods used to convey fuel cell education to students. The focus of this paper also describes the advantages of using the latest technology in education tools such as mobile games that can help to promote motivation and engage students to learn and understand more about fuel cells.

2. LITERATURE REVIEW

2.1 The Importance of Fuel Cell Study

In creating a demand for fuel cells, the public needs to be exposed to and understand the benefits of the technology itself. With a clear understanding especially from the industry and the public, these alternative technologies will fully then be accepted and lead to the demand for the use of fuel cell-related products (Fang et al., 2021). Learning about fuel cells is intended to help key target audiences who are involved in the use of hydrogen and fuel cell technologies, both directly and indirectly. The material provided should be objective and technically correct. Additionally, through outreach, education, and training for second-generation clean energy experts, it can raise broad knowledge and awareness of the advantages of hydrogen and fuel cells (Bezdek, 2019).

A complete set of measures is needed to manage and run these new energy systems if hydrogen and fuel cells are introduced on a large scale. Fuel cells will become part of our daily routines where fuel cell energy will be used in generating electricity at homes or for transportation. Aside from that, one of the main justifications for the implementation of fuel cell education at every level is the necessity to secure the human capital required to satisfy the unique demands of the widespread usage of hydrogen and fuel cells (Al-Amin & Doberstein, 2019). Education programs at higher levels such as in universities are one of the places in provide the basis for understanding fuel cell technologies. It also provides the training which is necessary for building our future workforce (U.S. Department of Energy, 2019). The integration of hydrogen and fuel cells into the current energy and transportation systems will be significantly aided by universities and research facilities.

According to the U.S Department of Energy (2016), it is reported that there is an increase in terms of potential jobs offered especially in the fuel cell and hydrogen industries. Jobs will be created in the industries that manufacture and provide the fuels these systems require, like hydrogen. Experience in science and engineering relevant to product and technology development is necessary for these positions (U.S. Department of Energy, 2019). As to the analysis, extensive market penetration may result in the creation of 180,000 new jobs in the US by 2020 and 675,000 jobs by 2035. Various promising careers in the line of fuel cell technologies such as mechanical, chemical and electrical engineers, chemists, laboratory

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technicians, factory workers, power plant operators, hydrogen productions technicians and much more. Various initiatives have been carried out by the U.S. Department of Energy in the education of fuel cells to the future generation because they are the ones who will handle this new technology intensively. It is anticipated that the business will grow significantly as different fuel cell applications gain market share. Businesses that design, produce, run, and maintain fuel cell systems will have openings for employees (Fang et al., 2021).

Meanwhile, in Malaysia, there are various action plan time frames for fuel cells and hydrogen energy has been developed to increase public acceptance and awareness. In the 2015 report Carbon Free Energy: Roadmap for Malaysia, the Academy of Science Malaysia suggests, among other things, exposing and effectively raising awareness through the promotion of fuel-cell-based project learning in public education curricula and working toward the creation of fuel cell courses at specific schools and universities (Academy of Science Malaysia, 2015). Some strategies have been formulated to initiate, improve, and nurture the hydrogen and fuel cell industries. The strategy includes building adequate capability building in human resources in the hydrogen industry (Akademi Sains Malaysia, 2017). Moreover, the fuel cell educational programs are expected to be able to equip the targeted end users with the tools to assess the competing technologies concerning to environmental awareness (Tajuddin et al., 2021). Hence, it’s become one of the important issues to ensure that fuel cell usage is not just one of the technological advancements but is one of the crucial steps in preserving and conserving the environment for a better life.

Recently, people all over the world have been concerned about the reduction of carbon emissions regarding environmental and health benefits. Germany, Japan, the United States, and China are among the major and developing economies that have committed at the national level to expediting the assessment of hydrogen energy and infrastructure solutions in order to capitalise on their advantages in terms of both energy and the environment (Al-Amin & Doberstein, 2019). Therefore, the reinforcement of green energy has become an important issue to discover the limitations and barriers to the successful application of renewable energy in cities and rural areas of the individual country along with its geographical area and natural resources (Fang et al., 2021). An analysis of the number of improvements is also required to adopt renewable energy acceptance among society so it can be implemented intensively.

Moving forward on the Eleventh Malaysia Plan (2016–2020), one of the focus areas is to strengthen the enabling environment for green growth. To fulfil the objective, communication, education, and public awareness (CEPA) programs will be carried out at all levels of society. Ensuring public awareness of environmental issues, adapting to and mitigating climate change, protecting natural resources, and the contribution of green growth to increased productivity are the aims of this campaign. All parties involved the federal and state governments, the business community, academic institutions, non-governmental organisations, and society at large will therefore be imbued with a sense of collective responsibility for concerted, all-encompassing activities aimed at improving the standard of living. Enhanced cognizance and consciousness will eventually result in modifications to the societal perspective, conduct, and customs (Eleventh Malaysia Plan, 2015). Thus, fuel cell education can raise awareness generally about the importance of protecting the environment, especially from greenhouse gases, and empower the next generation with a passion for clean energy for a brighter future.

Malaysia is one of the countries from all over the world that have considered application of the green technology as one of the important solutions to identify the issues of energy and environment gradually (Zakaria et al., 2023). Unfortunately, until the government can successfully influence public opinion to support the use of renewable energy, scientific technology and the suitability of renewable energy resources by themselves will not be able to assist Malaysia in implementing the successful use of renewable energy sources around the country (Qazi et al., 2019). To achieve long-term energy supply sustainability, the government has already taken steps in the 8th Malaysia Plan (2001–2005) to establish new methodologies for assessing the availability of renewable energy and encouraging the use of renewable resources. The objective was to address the nation's increasing energy demand by allocating 5% of the entire energy supply

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mix to renewable energy sources. Fuel cells are among the alternative energy sources because, after solar energy, they are thought to be the cleanest renewable energy sources with the fewest environmental problems (Abdullah et al., 2019).

Fuel cells provide a cleaner and more efficient mechanism for energy conversion. The flexible chemical-to-electrical energy releases zero carbon emissions during the conversion and can be considered safe for the environment. Furthermore, fuel cells work well with sustainable energy sources like hydropower, wind power, and solar energy. Sustainable hydrogen production from renewable energy sources doesn't release any carbon dioxide (Santhanam et al., 2017). Hydrogen production using photocatalytic water splitting from solar energy offers a promising option to generate hydrogen from renewable resources. Due to the fact that these systems can produce electricity anywhere and whenever needed, they are genuinely sustainable (Staffell et al., 2019).

The primary issues with producing energy from renewable sources are inadequate knowledge of effective procedures and equipment operation, ineffective energy management, and existing technology (Abdullah et al., 2019). One challenge that Jordanian renewable energy companies confront, for instance, is finding qualified engineers and technicians with expertise in renewable energy technologies and planning. About 100,000 new employment are expected to be created in Malaysia as a result of the RE Policy, according to estimates (Qazi et al., 2019). The reason for this is the current inadequate and outdated energy and renewable energy education. Particularly at engineering colleges and faculties, renewable energy education is still a relatively new subject in both general education and higher education. In contrast to developing or adapting renewable energy technologies, most researchers focused on theoretical analysis. While renewable energy technologies, application sources, and potential were the main topics of much earlier research on the subject, renewable energy education was not included. As a result, there is a significant gap in the knowledge of and research into practical concerns, as well as in communicating these concepts to the general public and relevant local companies (Wang et al., 2022).

It is crucial and necessary to begin serious research and field studies with the goal of analysing and evaluating current energy and renewable energy education programs due to the growing need for human capital in the renewable energy industry. These could involve, but are not limited to, concerns about currently available courses, the credentials of teachers, and the future contributions of scholars and students in resolving energy-related challenges and removing obstacles that impede the use of renewable energy in various economic sectors. There is a possibility that the market would experience a shortage of qualified engineers and technicians in the absence of appropriate education and training programs due to a lack of awareness and limited understanding about energy and renewable energy technologies in society (Wang & Guo, 2021).

Awareness and education are two distinct yet interconnected concepts that play vital roles in shaping knowledge, attitudes, and behaviours (Glavič, 2020) . Awareness refers to the knowledge or understanding of a specific issue or situation. It involves recognising the existence of a problem, its causes, effects, and consequences for individuals and society. An individual that is aware of fuel cells might recognise them as an alternative energy source but lack knowledge of their functionality, benefits, or potential applications. On the other hand, education encompasses a broader process of acquiring knowledge and skills through structured learning (Schinkel, 2020). Someone with a good education in fuel cells would understand their mechanics, applications, advantages, and disadvantages.

One of the primary goals of any educational program is to prepare the population for its future, so it is very critical to carefully assess any renewable energy education such as fuel cell education for societal needs in the future. Therefore, the main idea of fuel cell education is to teach students about hydrogen fuel cells as a step towards creating a clean and sustainable future. Another barrier to renewable education in Malaysia is the lack of advanced technology for the generation and the lack of awareness of the benefits of renewable energy resources (Abdullah et al., 2019; Al-Amin & Doberstein, 2019). The capacity of current institutions involved in human resource development must be examined and developed in accordance with

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the specific education and training needs in the field of renewable energy. In addition, the goal of courses or training sessions on renewable energy ought to align with the nation's growth plan. Fuel cell education, aiming to equip the next generation in Malaysia with the knowledge and skills to critically evaluate and contribute to this promising field. Furthermore, fuel cell education can serve as a catalyst for environmental awareness, highlighting the importance of mitigating greenhouse gas emissions and inspiring a passion for clean energy solutions for a sustainable future.

2.2 Understanding fuel cells

Fuel cell education does have connection and positive impacts on the public especially for students who we believe to be the potential end users of fuel cell technologies soon. Currently, a number of industrialised and emerging nations, including China, Japan, and the United States, have committed to increasing the use of fuel cell and hydrogen technology in order to take advantage of its advantages in terms of energy and the environment. Therefore, various strategies applied for disclosure and to increase knowledge about fuel cells were carried out.

For the past few decades, postgraduate courses on hydrogen and fuel cells have mostly been offered by a small number of universities and research centres. In terms of higher education, universities can act as training facilities, offering a foundational understanding of novel energy system components like fuel cells and acting as a "knowledge link" to connect the current energy supply systems with emerging ones. Advances in research and postgraduate education will be necessary to bring fuel cells and hydrogen closer to a financially viable energy system (Zawawi & Yasin, 2023). In 1996, Universiti Kebangsaan Malaysia (UKM) and Universiti Teknologi Malaysia (UTM) began collaborating on fuel cell research, which sparked interest in the country (Mah et al., 2019), establish the facilities required for doing research on fuel cell systems. Fuel Cell Institute UKM, which is currently the nation's centre for fuel cell research and development, was established as a result of the establishment of research institutions for fuel cells and hydrogen energy systems. Table 1 shows two of the universities in Malaysia that offer fuel cell education programs.

Table 1. Universities in Malaysia that offer fuel cell education

Universities	**Faculty**	**Postgraduate programs offered**
Universiti Kebangsaan Malaysia (UKM)	Fuel Cell Institute	Fuel Cell Engineering Hydrogen Energy Energy Policy and Management
Universiti Teknologi Malaysia (UTM)	Centre of Hydrogen Energy	Chemical Engineering

Source: Authors' illustration

It was different circumstances in lower education in Malaysia where there is no formal learning of fuel cells in any elementary or secondary public-school curricula. But certain subjects such as science, mathematics, chemistry design, and technology are interrelated to fuel cells that are implemented in the school curricula at the secondary level shown in Table 2 (Malaysia Ministry of Education, 2003a, 2003b, 2006a, 2006b, 2006c, 2012, 2015). Learning all these topics in certain subjects does at least give some basic knowledge for students to understand more about fuel cells in general. From a mathematical and scientific perspective, engineering offers a wealth of relevant, real-world issue scenarios that build upon and deepen students' prior knowledge of these areas. Throughout the mathematics, science, and chemistry curricula, engineering is taught as a subject that focuses on problem-solving. It discusses how mathematical modelling enhances and complements engineering design processes in order to solve engineering-based challenges (Ju & Zhu, 2023).

https://doi.org/10.24191/mjcet.v7i2.1296

Table 2. Summary of subjects interrelated to fuel cell in Malaysian secondary school curricula

Level	Age	Subject	Topics	Learning objectives
Form 1	13 years old	Science	Exploration of elements in nature	An introduction of variables of elements around us
		Design and technology	Design process, Project management.	As an exposure and awareness of the importance of design, aesthetics, and technology. Students can develop skills to communicate and create ideas and can be designers who cultivate critical thinking, creativity, innovation, and invention.
Form 2	14 years old	Science	Composition of water.	To determine the composition of water, test the presence of hydrogen and oxygen.
Form 3	15 years old	Science	Reactions between metals and non-metals	Explain how metals and nonmetals react, provide word equations for the reaction, and assert that the rates at which the metals and nonmetals react vary.
Form 4	16 years old	Science	Energy and chemical changes	Understanding electrolysis, Synthesising the reactivity series of metals, Understanding the production of electrical energy from chemical reactions
		Chemistry	Electrochemistry	Recognising the differences between electrolyte and non-electrolyte properties Examining molten compound electrolysis, voltaic cell analysis, electrolysis in industry evaluation, and analysis of aqueous solution analysis assembling an electrochemical series
Form 5	17 years old	Chemistry	Oxidation and reduction	Analysing redox reactions in electrolytic and chemical cells, evaluating energy changes in chemical reactions.

Source: Authors' illustration

Integrating fuel cell topics into the Malaysian school curriculum offers significant opportunities to enhance students' understanding of clean energy technologies, yet there are notable gaps in current educational practices (Basri et al., 2021). The existing science and technology curricula often lack a focus on fuel cells, which limits students' awareness of renewable energy solutions essential for addressing environmental challenges. To address this, stakeholders can incorporate fuel cell concepts into subjects like physics, chemistry, and environmental science, making the material more relatable.

The implementation of topics such as design projects or project development from an early age shows some efforts of the Ministry of Education of Malaysia in applying basic knowledge of engineering. A methodical approach to problem-solving is typically exhibited by students who are taught to apply engineering design processes to real-world situations. The students are capable of problem-solving, critical thinking, flexibility, creativity, and failure-based learning (Jamison et al., 2022). It is imperative to provide professional development and appropriate resources to scaffold teachers' understanding and pedagogical strategies in order to create an effective learning process, as the majority of teachers lack education related to engineering concepts and thinking (Patil & Kumbhar, 2021). In the meantime, fuel cell education is still not a part of the curriculum for most students in European schools. The contribution of hydrogen and fuel cell applications to the creation of a safe and sustainable energy future is hardly ever discussed in textbooks (Fang et al., 2021). Additionally, national school curricula in Europe do not include instruction on the sustainable use of energy, such as fuel cells, for elementary and secondary students (Pietrapertosa et al., 2021). In most European countries, teacher initiative and interest are what determine students' knowledge of future energy resource solutions, renewable energy sources, and energy efficiency at the elementary and secondary school levels.

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A National Energy Education Development (NEED) project suggested that learning about hydrogen and fuel cells should begin with K-12. K-12 is a term used in education in several publicly supported schools in countries such as the United States. It represents the grades from kindergarten (K) and the first grade through the twelve grade (1–12) (Alzarrad & Delduque, 2023). These programs aim to provide the use of hydrogen and fuel cell technology to instruct pupils nationwide in the United States the future generation of engineers, scientists, and end users. Hence, the "H_2 Educate!" program team has aided in developing teaching materials and curriculum for fuel cells and hydrogen. Fuel cell education may not be used as compulsory subjects in schools' curricula, but it can be made as an extra curriculum for teachers and students to gain more knowledge about hydrogen energy and its usage in daily life. This will eventually help to broaden technology acceptance and create a better future for fuel cells.

2.3 Learning fuel cell strategies

Since fuel cell education takes place at a higher level, the formal learning methods are usually through classes, lectures, or courses offered by the university or any related agencies. The U.S. Department of Energy's Fuel Cell Technologies Office, however, provided support in 2016 for the creation of fuel cell education curricula for lower education. These curricula include general education classes, specialised science and engineering courses, minor and concentration programs, curriculum modules, internships, lab classes and kits, and textbook chapters (Baxter & Keller, 2016). In 2014, a collaboration of researchers in the United States and Japan conducted an experiment to teach fuel cells by using problem-based learning strategies (Porat et al., 2023). It is thought that problem-based learning (PBL), is crucial for engineering education. PBL has been used to effectively conduct several experiments in the real world and has been a tool for creative engineering design that can boost creativity. On top of that, they combined the PBL strategies with the virtual environment created as complementary activities to motivate students in the learning process (Dutta et al., 2022). Students were given a problem regarding their daily lives and had to design a green technology car for the future as their project. Throughout the learning process, it's indirectly shown that students are eager to learn about fuel cells because it's more meaningful to them as they need to build a fuel cell car to solve the problems.

With the advances in learning technology, anybody who wants to learn about fuel cells can take the initiative to undergo various learning resources that are created on-site. Table 3 shows some websites that have been developed to help the public, especially for students or teachers to get a better understanding of hydrogen energy by using the learning resources provided. Educators can make full use of all the learning resources available online. A variety of materials can be used as learning aids and tools such as lesson plans, learning modules, quizzes, and activities regarding fuel cell education. There are also models and fuel cell project kits sold online. The use of these learning resources that have been provided to some extent can encourage teachers and students to explore fuel cells in more fun and effective ways.

To facilitate successful learning experiences, these learning strategies try to suggest creative applications of cutting-edge educational approaches and technology. The way that technology and learning methodologies interact enables the student to take charge of their education (Bakan & Bakan, 2018). Even though fuel cell education in higher education still uses traditional learning strategies such as training courses and lectures, it seems no longer sufficient in an informal learning context. Thus, it's imperative to use resources that help raise student involvement, particularly for younger students. Learning through a project-based environment can also give a meaningful learning process for the students. At Rensselaer Polytechnic Institute, the engineering design course used a pedagogical approach that involved designing, building, and testing a microbial fuel cell technology over a 15-week semester for second-year undergraduate students (Jamison et al., 2022). The project aims to reduce the amount of energy used for wastewater treatment in New York. They must investigate and assess the use of microbial fuel cell (MFC) technology as a secondary biological process in wastewater treatment plants (WWTPs). This learning strategy not only provided design and research experiences on fuel cells to the students but also allowed them to learn basic skills of communication and team management.

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Table 3. Websites that provide learning resources for fuel cell education

Author	Purpose	Learning resources	Reference
U.S. Department of Energy (DOE)	Delivering objective, factual, and technically correct information to important target audiences involved in the utilisation of fuel cells and hydrogen, including prospective end users, instructors, and students at all levels.	Course materials for lesson plan and activities Quizzes, Information fact sheet.	(Office of Energy Efficiency & Renewable Energy, 2017)
National Fuel Cell Research Centre, University of California	Providing information about fuel cell energy and other renewable energy such as solar, wind, and hydroelectric by using online learning.	Online tutorial	(National Fuel Cell Research Centre, 2017)
BrainPOP educators	Provide interactive learning materials for teachers and students to learn fuel cells.	Lesson plans Classroom aids Support video New teaching resources	(BrainPOP Educators, 1999–2017)
Fuel Cell Store	Selling various models and project kits that can be used as learning tools	Lesson plans Learning tools	(Fuel Cell Store, 2017)
Science Education for Public Understanding Program (SEPUP)	Providing various teaching resources and learning modules to teachers.	Fuel cell learning modules Teaching resources	(Lawrence Hall of Science, 2017)

Source: Authors' illustration

3. FUEL CELL THROUGH GAME-BASED LEARNING

Game-based learning, or educational gaming as some have dubbed it, has become a popular teaching and learning method in the education sector in the modern day. When employing game-based learning as a teaching and learning method, students will learn more effectively and retain more knowledge and skills than when using a standard syllabus-based approach (Ishak et al., 2021). The outcomes of playing games may be intended or unintended. Nonetheless, playing games can provide many of the essential requirements for learning games, including passion, enthusiasm, structure, motivation, ego fulfilment, adrenaline, creativity, social connection, and emotion. There are some studies suggesting that learning through games has already gained acceptance as one of the good training tools for education. It is because the simplicity and the cost-effectiveness make games preferable for students as they enjoy playing over learning (Chen et al., 2020).

Game-based learning has been proven to be a useful learning tool. It can stimulate the cognitive development of students and their potentialities (Bakan & Bakan, 2018). Playing games will involve motor activity, language, student's symbolisation capacity, and skills acquisition so they can start building their learning. Games encourage students to actively learn by helping them to build their comprehension and validate the information that they are taught by the teacher. Students can begin learning about their surroundings and developing their independence and communication abilities by interacting with the activities and exploring them (Lucas, 2017). In addition to receiving an education, students will pick up skills more easily. The game serves as a tool for students to learn and internalise concepts since it allows them to freely engage with their surroundings and give their actions value. This has an indirect impact on how they will grow and mature as adults in the future (Suraini & Aziz, 2023).

https://doi.org/10.24191/mjcet.v7i2.1296

Utilising games is one method to support pupils' autonomous research of differentiating issues. Games can engage and motivate students throughout class without detracting from the instructional process. Learning more incomprehensible content can be delivered to learners through simple visual representations and interactions (Maaruf et al., 2022). Students can develop an intuition even for systems that have no parallels in their everyday lives because to the simple graphic representations and gaming features. In the context of educational games, learners will learn by playing. While participating in the game scenario, students are working together in groups for multiplayer games or independently on a set of learning objectives for single-player games. These activities will increase pupils' enjoyment and engagement with the material (Bulut et al., 2022). Not only that, but the games also support and provide adaptive learning experiences for the students to explore and learn. The fact that a game learner needs to apply previously acquired knowledge to play and increase their score also encourages the recovery of prior understanding.

Game-based learning involves mapping course material into a virtual environment for learning. Repeated self-study, constant interaction, and feedback can all boost motivation and interest in the material. As a result, it might successfully accomplish learning (Ishak et al., 2023). It gives students real-world assignments and a supportive environment for practicing critical thinking. It also helps them to test out different viewpoints and strategies without posing a significant danger to themselves (Hanif, 2020). The game fosters critical thinking as well as the growth of social and personal skills in addition to knowledge acquisition. While playing, students will eventually use their language abilities, communication, and collaboration skills that will encourage them to be creative and enhance their problem-solving skills. It is because the game provides successful learning environments that support multisensory in active and experiential situations using problem-based learning (Dutta et al., 2022). However, educational games are especially suited to teach higher-order skills such as multitasking, decision-making, or strategic vision that are not typically accessed through formal examination.

To create engaging and significant learning experiences, educational games have been included in the curriculum. One study examined the efficacy of creating educational computer games using concept maps in an elementary school natural science course. It found that incorporating concept maps into game scenarios could both increase student achievement and reduce cognitive load (Bedard et al., 2019). While playing educational games it produce chemical changes in the brain that can promote learning and it was proven in some studies that learning through educational games is better than conventional learning methods such as lectures or attending courses (Pellas et al., 2019). Game-based learning is divided into two types of categories which are traditional games and digital games. Traditional games are games explicitly designed as gameplay with specific functions of school learning such as cards or boards. It is built in the form of real objects and can be touched and played by the students under the supervision and monitoring of teachers. Meanwhile, digital games it's also designed for educational purposes similar to traditional games but they use platforms such as computers, video consoles, and mobile applications to deliver the learning context (Coleman & Money, 2020). Table 4 shows a comparison between several game-based learning and the features that each game provides for the learning purpose.

Table 4. Comparison of various game-based learning

Criteria	Mobile games	Computer games	Video games	Non-digital games
Mobility	✓			
Easy access	✓			
Interaction with augmented reality	✓			
Real-time score	✓	✓	✓	
Interaction between students	✓	✓	✓	✓
Interaction with environment				✓
Face-to-face learning with the teacher				✓

Source: Author's illustration

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The market for educational games has recently seen the arrival of mobile solutions. An emerging field of study in education is the integration of gaming and learning with technological assistance (Szymkowiak et al., 2021). The combination of mobile technology and pedagogy has created a learning environment that is more effective and efficient since it empowers the student to take an active role in their education. It will be active learning and more focused on the students while teachers will act as their facilitators throughout the learning process. Consequently, it can support the student in keeping up a high degree of motivation, engagement, and involvement throughout the entire learning process.

Due to its mobility, mobile technology offers anytime, anywhere access to information, processes, and communication, opening the way for new forms of learning and performance assistance in the field (Crompton & Burke, 2018). Aside from that, learning strategies are being developed by mobile games. One such strategy is the "Just-In-Time" strategy, which allows learners to quickly and readily access material and learn when needed (Llanos et al., 2021). For example, anyone can make use of the time while waiting in queue for public transportation with their mobile devices.

Non-digital games usually will be played in class during formal lessons or maybe outside the class during extra-curricular activities. Interactions between students and between teachers have a significant influence on learning in a classroom setting. Face-to-face encounters expose participants to human expressions, physical actions, and conversational tones, in contrast to computer-based digital gaming interactions. Therefore, employing instructional card games as a platform for game-based learning could improve student-to-student and teacher-to-student direct interpersonal connection (Lei et al., 2022). While playing non-digital games students are expected to manipulate their cognitive processes when they are free to take the materials in which they have interest and touch everything that is around them.

Students who have interaction with augmented reality (AR) while playing mobile games show more interest in playing and engagement rather than playing video games (Hussein et al., 2019). Their preferences show significant statistical differences between the two types of games. Digital games leverage the social component to involve the community in the learning process and provide self-assessment tools like points and achievements for completing stages. As for the non-digital games, the score or results of the games will be determined at the end of game play which indicates late feedback systems for the students (Aguilera & de Roock, 2022). Digital games also use interfaces to generate visual feedback on devices that involve human interaction between the students who played the game.

Undoubtedly, game-based learning is a useful tool for encouraging innovative teaching methods, and research indicates that mobile games can help students learn by offering difficult experiences that encourage intrinsic fulfilment and opportunities for real learning by letting students freely explore the material presented (Chang & Hwang, 2019).

3.1 Mobile technologies for education

Over the past 20 years, mobile technology has been progressively incorporated into educational settings, leading to the majority of people carrying around their own personal, compact computers with remarkable processing capacity, such as laptops, tablet PCs, cell phones, and e-book readers (Prokofyeva & Boltunova, 2018). Mobile technology is a learning tool that has considerable potential for use in both regular classrooms and outdoor informal learning settings due to its combination of powerful processing power, portability, wireless communication, and context-sensitive features (Yu et al., 2021). The use of mobile devices and technology to assist, enhance, and broaden the scope of teaching and learning is known as mobile learning (Ishaq et al., 2021). Compared to PCs, mobile devices like phones and tablets are more compact, wireless, affordable, straightforward, and manageable. They can be utilised in a variety of fields, particularly education where learning has become more mobile (Crompton & Burke, 2018). Mobile gadgets, including phones and tablets, have grown so quickly that they are now an essential part of everyone's life. Many respondents in nearly every country questioned claim to own a mobile device, even if it isn't a smartphone. Thus, the term "digital native" or "Net Generation" refers to today's youth and young

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people who were raised in a mobile and technologically advanced environment.(Magsamen-Conrad & Dillon, 2020).

Even though there are multiple definitions of mobile learning or mobile technology for education each of them still focuses on the same idea. It has been demonstrated that, whether learning activities were carried out in a classroom or on the job, mobile devices were crucial (Ishaq et al., 2021). Additionally, mobile devices can be utilised for both non-formal and formal education. The expansion of the learning environment allows students to exhibit scientific knowledge and principles in settings other than the lab or the classroom, as well as to examine additional science phenomena in real-life (Criollo-C et al., 2021). A handphone user survey by the Malaysian Communication and Multimedia Commission (2010–2014) reported that 27.8% of students in secondary schools used handphones daily. The report also found that about three-quarters of users (71.4%) constantly check their handphones even when it does not ring. Based on the survey, 33.9% of school-going youngest children of the respondent own a handphone. The mode age of first ownership is 13 to 15 years old. Based on the statistics of smartphone users in Malaysia from 2010 to 2020 shown in Fig. 1, it seems like the usage of smartphones also continued to grow over the years (Masaat et al., 2023). The number of Malaysians who used smartphones climbed from 3.14 million in 2010 to 29 million in 2021 shows that frequent use of mobile technology can allow them to benefit from it towards more beneficial things like learning formal education rather than using it as entertainment. With the usage of technology, students nowadays are engaged in new ways of learning that can provide new content and facilitate information access wherever and whenever they are.

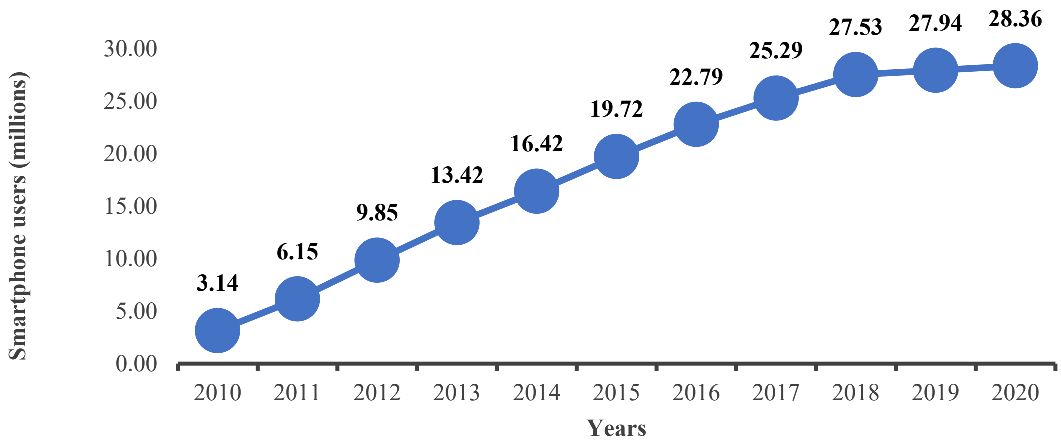

Fig. 1. Statistics of Malaysian smartphone users 2010–2020.

Source: Masaat et al., 2023

COVID-19 has also accelerated the adoption of smartphones and digital devices, significantly impacting game-based learning. The increased accessibility provided by various organisations has enabled more individuals to engage with educational content through interactive gaming platforms. This transformation highlights the potential of technology to enhance learning experiences in a rapidly changing world (Jonnatan et al., 2022). This period of rapid technological adoption also saw a surge in the development and implementation of game-based learning. With students spending more time online, educators and developers sought engaging and interactive ways to deliver educational content remotely particularly in specialised fields like fuel cell technology.

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Also, despite not being within range of mobile service, consumers are increasingly viewing their phones' screens due to the ease and mobility that these devices offer. It has become an ordinary occurrence to see someone operate their mobile phone while walking, sitting, or waiting and the action of looking at a mobile phone display has become a ubiquitous part of modern life, occurring in public and private spaces alike (Magsamen-Conrad & Dillon, 2020). The usage of mobile technologies in daily life is also supported by data from a report in Fig. 2 by Ernst & Young Global Limited (Ernst & Young Global Limited, 2016, 2017). The survey was conducted on 1018 respondents in Malaysia through an online questionnaire. According to the survey report, people's modes of engagement with technologies and consumption behaviours are changing because of the shift from a tech-savvy to a tech-smart customer base. Most Malaysians (91%) use smartphones in their daily life and over one-third of Malaysians reportedly spend more than 5 hours a day which is approximately 13.7 hours per day, 4.2 hours on their mobile devices. Moreover, almost 30% of Malaysians play games using mobile devices such as hand phones or tablets. It's does show how connected and engaged Malaysians to the digital environment.

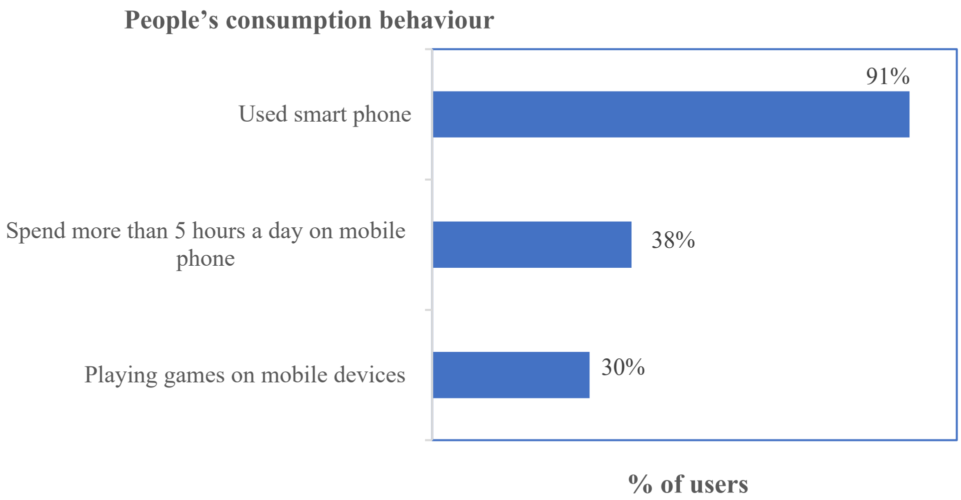

Fig. 2. Statistic of percentage users that own a smartphone, time spent, and playing games on mobile devices in Malaysia

Source: Ernst & Young Global Limited, 2016, 2017

Mobile games are the ideal option for delivering instructional information because of the growing popularity of mobile technology in the market. They also have a great deal of potential to introduce students to complex concepts in a fresh and engaging way. In and out of the classroom, it offers a multitude of chances to enhance learning and performance. In the lab, outdoors, or somewhere in between, students can investigate how learning occurs (Camilleri & Camilleri, 2023). By taking the chances on this situation, the usage of mobile games as learning tools in conveying fuel cell education seems to be the best option as it can reach easily the target population which is the secondary students. It makes sense to assume that this generation will find mobile gaming to be highly appealing. It is true that most young people enjoy using their phones for gaming and browsing. The widespread adoption of smartphones in Malaysia, particularly among students (Jonnatan et al., 2022), provides a readily available platform for delivering engaging educational content. This, combined with the rise of game-based learning, presents a unique opportunity to engage the next generation in fuel cell technology through familiar and interactive means.

For fuel cell education, both competency-based and objective-based games can be valuable tools, but objective-based games should be more widely explored. Competency-based games focus on developing

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students' skills, such as critical thinking, problem-solving, and practical application of knowledge. While objective-based games for fuel cell education not only help students achieve specific learning outcomes but also foster environmental awareness (Laine & Lindberg, 2020). By setting clear goals related to the environmental impact of fuel cells, such as reducing carbon emissions and increasing energy efficiency, these games encourage students to explore the role of renewable energy in combating climate change. Through interactive scenarios, students can simulate real-world applications of fuel cells, such as in transportation or power generation, and see firsthand how clean energy technologies contribute to a sustainable future. This structured approach ensures that students not only grasp the technical aspects of fuel cells but also develop a deeper understanding of their potential to reduce environmental harm, aligning with broader educational goals of promoting environmental awareness.

4. CONCLUSION

Fuel cells are a promising clean energy technology for Malaysia’s future, converting fuel into electricity through electrochemical reactions. Despite significant advancements in the past 13 years, the industry still faces technical and commercial challenges. To address these, early education on fuel cells is essential in preparing future generations to meet the demand for skilled professionals. Mobile games offer an innovative approach to fuel cell education by making learning interactive and engaging. These games allow students to explore complex fuel cell concepts both inside and outside the classroom, enhancing motivation and understanding. A gap analysis highlights key areas requiring attention to ensure the success of fuel cell education. Currently, educational materials targeting younger students are insufficient, and school curricula lack comprehensive coverage of fuel cell technology. Moreover, mobile games as educational tools are not yet fully integrated into learning practices.

Therefore, several key areas of focus for future work emerge from the current review. Firstly, a need to develop a fuel cell education module focusing targeted group which is students at the secondary level. By considering the student’s prior knowledge, it is suggested to relate the content of fuel cell education with the standard school curricula. This will be a good starting point in ensuring the exposure to fuel cells is easier to understand. Secondly, using mobile games as learning tools is suggested to deliver the learning content for fuel cell education. Mobile games seem to be the best choice that can attract young learners because they can promote learning engagement and motivation. Lastly, the fuel cell education module must be tested on the targeted group to ensure the effectiveness of the module to be implemented overall in the future.

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CONFLICT OF INTEREST STATEMENT

The authors agree that this research was conducted in the absence of any self-benefits, commercial or financial conflicts and declare the absence of conflicting interests with the funders.

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AUTHORS' CONTRIBUTIONS

Nur Fadhilah Abdul Jalil: Conceptualisation, analysis and writing-original draft; **Umi Azmah Hasran**: Project administration, supervision, editing, and validation; **Siti Fadzilah Mat Noor**: Supervision, writing-review and validation; **Muhammad Helmi Norman**: Supervision, writing- review and validation.

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