EXPLORING THE POSSIBILITY OF EXPOSING FUEL CELL TECHNOLOGY THROUGH DIGITAL GAME TO PRIMARY LEVEL CHILDREN

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ABSTRACT

Educational digital game is the best pedagogical approach to enhance STEM education especially for children in the 21st century. STEM education is well known as a difficult subject and children have problems to relate to the interdisciplinary of each STEM subject. While struggling with the issue, fuel cell technology is an emerging STEM discipline that promotes an environmentally friendly approach by reducing carbon production. In fact, fuel cell technology has been noticed as a field that requires the use of interdisciplinary STEM knowledge. However, fuel cell technology's basic concepts might be difficult to understand by children at the primary level. In this study, we aim to explore the possibility of using digital games to expose fuel cell technology to primary level children. This study uses a qualitative approach by reviewing selective existing literature to support our argument. The data has been reviewed and mapped thematically. Evidence from the literature shows that fuel cell has the potential to be exposed to children as they learn the basic of energy and electricity through science textbook from the age of 10 years old. In fact, children are obsessed with playing digital games. If the fuel cell concept is integrated into game mechanics, it allows them to individually explore the game and integrate the fuel cell learning concepts in a playful environment. However, further research needs to be conducted to empirically ensure this ideology. Especially the feasibility of children's acceptance towards fuel cells and whether integrated fuel cell content can be learnt by children through digital games.

Keywords: Digital game; STEM Educational Game; STEM Education; Fuel Cell Technology; Children Game

INTRODUCTION

STEM education is the core towards global economics and development. Teaching and learning for STEM subject has been influence by digital technology. Instead of learning at school, those integrated subject can be experienced outside school through digital games. Digital games are one of the best pedagogical approaches for STEM learning environment (Ishak et al., 2021b). Even though STEM subjects are commonly taught as individual subject, students must be able to make a connection within these four disciplines to understand nature and real-world solving problem (Bryan et al., 2016; Freeman et al., 2014; Koehler et al., 2016; Shahali et al., 2017). Digital games can provide an interactive virtual world that imply the application of each STEM disciplines (Ishak et al., 2021b; Marcelo Leandro et al., 2018). Among the wide range of STEM disciplines, fuel cell technology is one of the best examples to represent the importance of the multidisciplinary of each STEM subjects.

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Bridging fuel cell technology and primary level STEM education is not easy. Fuel cell is a green technology that minimize carbon emissions. Several developed countries like the USA, the UK, Australia, Canada, China, France, Norway, Germany, Japan, and South Korea started to develop and deploy hydrogen-power fuel cells for various applications such as heavy-duty vehicles, delivery fleets, locomotive and maritime vessels (ACT News, 2018; Deign, 2019). Meanwhile, the ASEAN region also noticed this emerging and demanding clean fuel for transportation (Fawthrop, 2020; Li, 2019). Malaysians also noticed the major markets for fuel cell industries mainly for stationary power and portable power (Wan Daud et al., 2017). In 2019, Sarawak Energy Malaysia launched the first integrated hydrogen production plant and refuelling station in South East Asia (FuelCellWorks, 2019). This emerging industry is being taught only at the tertiary level education (Hasran et al., 2019; Wan Daud et al., 2017).

The curriculum or syllabus for fuel cell technology is mostly present at the tertiary level of education in the field of engineering, as a part of STEM disciplines. Most graduates and experts in this field are mostly located under the department of chemical engineering or renewal energy. In Malaysia, few public universities emphasise research on fuel cell technology such as the Fuel Cell Institute (SELFUEL) at the National University of Malaysia (UKM) and the Centre of Hydrogen Energy (CHE) at the University of Technology Malaysia (UTM). Due to the complex scientific concepts, hydrogen and fuel cells are still not part of the syllabus for school children (Reijalt, 2010). Reijalt (2010) reported that the role of hydrogen technology as a sustainable future energy is rarely included in the textbook in European countries. This lack of exposure to the hydrogen-power fuel cell concept at an early-stage leads to awareness issues.

Primary and secondary educational systems have developed curriculum that might be related to the fuel cell technology. Electricity has been known as one of the popular and important topics being taught to children in school (Settlage & Southerland, 2007). In the Malaysian syllabus, these topics are covered in the *Science Standard 4 and 5* textbooks (Abd Karim et al., 2020; Anwar et al., 2019). Meanwhile, after children enter secondary education, they learn about electrochemistry. Electrochemistry is an important process in fuel cell to produce electricity, however it has been reported as one of the hardest topic for students to learn in school (Lay & Kamisah, 2018). Recently, since hydrogen and fuel cell technology became in demand from the need for global green technology, there must be a mechanism to promote and introduce the fuel cell technology concept to children. In fact, electricity is one important power source for human need. This early exposure might help children relate what they learn about science in school to real usage applications.

The potential practice to promote this fuel cell technology concept at an early age might be useful through digital game. Digital games are a suitable media for personalization of learning in the 21st century (Din, 2015). This is due to the nature of games. Games are envisaged as learning tools to give experience with tailored pedagogy, curriculum, media and environment to meet learners' different learning needs and aspirations that incorporate technology and the use of mobile devices to help all learners achieve the optimum levels of learning beyond what could be imagined just a few decades ago (Din, 2015). Mobile gaming has become the third most popular entertainment platform for various ages. The digital gaming culture takes the form of play activities among children. Children in the 21st century are well IT literate and have been exposed to digital gaming via mobile devices (smartphone, tablet, computer) at an early age. The advanced graphical interactive system offered by game applications will allow the fuel cell technology concept to be integrated into playable game mechanics. Most studies report that using digital games is highly influential for a better conceptual learning in playful environment regardless of formal or informal contexts (Becker, 2017; Dadure et al., 2021; Elsattar, 2017; Huang et al., 2017; Ishak et al., 2021b; Norizan & Nor Azan, 2017; Pilegard & Mayer, 2016; Qian & Clark, 2016; Rozhkova et al., 2017; Tan et al., 2016; Tsai et al., 2016). By doing so, children can experience how the fuel cell technology works and constructively relate to prior scientific facts they have learnt.

Throughout this paper, we justify our idea to expose fuel cell technology to children. We devised a central question of how fuel cell technology can be presented to primary level children through a digital game in the Malaysian context. Hence, this paper serves as a conceptual foundation to explain our ideology for exposing children to fuel cell technology through a digital game. Data from selected literatures are gathered and synthesized thematically to support this argument. The comprehensive explanation of this argument is presented into four major themes which are the foundation of fuel cell technology; fuel cell as a STEM discipline; fuel cell in the primary curriculum; integrating fuel cell into games; and future perspectives.

FUNDAMENTALS OF FUEL CELL TECHNOLOGY

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Fuel cell technology falls under the engineering field (mostly chemical engineering) that is associated with renewal energy. The study of fuel cells begins in 1839 after it was invented by W. Grove. The early version of the fuel cell is subsequently modified in 1842 and becomes an electrolytic cell. About 47 years later, the first fuel cell prototype is constructed. Fuel cells require the use of hydrogen and oxygen gases to generate electric power. In general, fuel cells are defined as a device that converts chemicals from one form into another and produces energy (power). Hydrogen has the highest fuel value compared to other chemical. The H-H bonds in hydrogen molecules produce maximum energy and have the highest fuel value (Santhanam et al., 2018). Due to this reason, fuel cells are considered as a green technology because the level of carbon emission is almost zero. Hence, the use of fuel cell technology helps sustain a better environment and reduce greenhouse effect. This field of study is developing, and most countries started implementing fuel cell technology as power supply (Figure 1). Fuel cells application are mostly being use in stationary power production, transportation, micropower system, space, and the military.

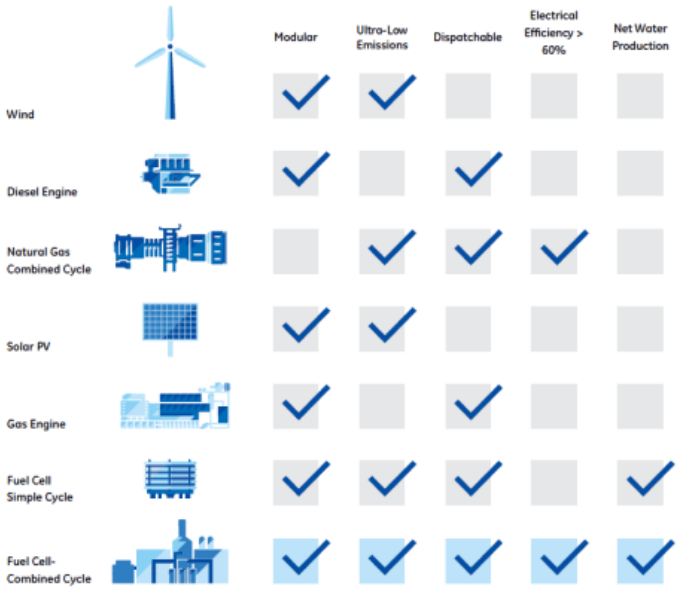

Figure 1: The benefits of fuel cell technology (Owens & McGuinness, 2016).

Hydrogen is the major source for fuel cell device since it is the most abundant chemical elements in our planet. The hydrogen energy is converted from renewable energy resources mainly from water. The initiative is to minimize the use of non-renewable energy consumption. There are several sources of renewable energy include solar, wind, hydro, biomass, geothermal, tidal, and hydrogen. The hydrogen element is the most common element in the universe. However, hydrogen in its gaseous form needs to be converted the chemical reaction of electrolysis (Revankar, 2019). Hydrogen production through electrolysis (PEM electrolysis) allows the simple decomposition of water into hydrogen and oxygen ($H_2O \rightarrow H_2 + ½O_2$) (Figure 2). Hydrogen storage makes fuel cells more practical as it can be stored in a safe, compact, efficient, and economic manner. It can be stored as compressed gas, liquid, solid-state or chemical based.

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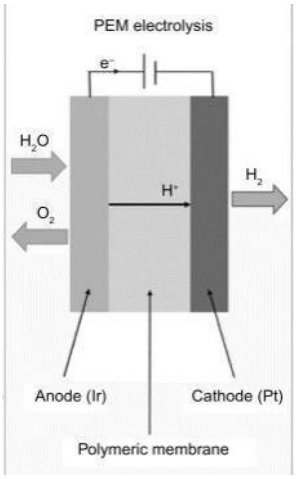

Figure 2: Hydrogen production through electrolysis (Revankar, 2019).

A fuel cell basic configuration consists of the separation of two electrochemical cells which are the anode and the cathode. Also known as sandwich configuration, a compact fuel cell consists of a polymer electrolyte membrane (PEM); an electrode (anode and cathode); a hydrogen (anode side) and oxygen (cathode side) flow field; and a bipolar plate. The hydrogen gas is supplied and flown through the channel on the anode side while oxygen is channelled on the cathode side. Oxygen flows directly from the air. The platinum catalyst of the anode ionises the hydrogen gas into hydrogen ions and negatively charged electrons. PEM only allows positively charged ions to pass through to the cathode while negatively charged ions will pass through the circuit and produce electricity. On the cathode side, electrons and positively charged hydrogen ions combine with oxygen to form water. The water flows out of the fuel cell. Figure 3 summarise the process of how fuel cells work.

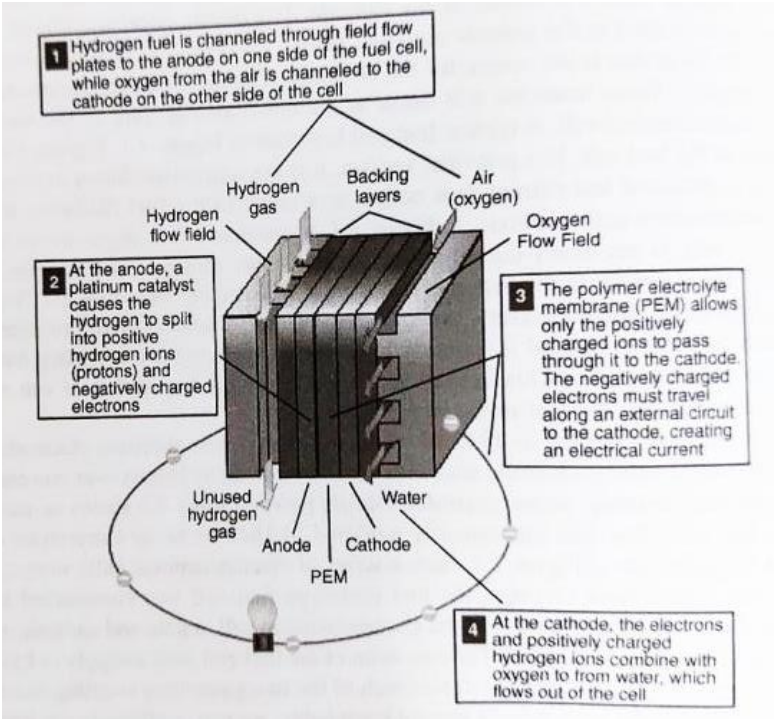

Figure 3: Basic configuration of a compact fuel cell (Santhanam et al., 2018).

Fuel cell technology is beneficial to the society. It is not just environmentally friendly but also reduces the consumption of non-renewable energy. The implementation of fuel cell technology will give help reduce the greenhouse effect, high energy conversion efficiency, integrated power sources, localised power generation, with an unlimited energy source of power (Santhanam et al., 2018). We strongly support that the basic of fuel

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cell knowledge is introduced at an early age since the world is trying to achieve a zero-carbon emission society. Since children are exposed to the use of battery in power generation, it is appropriate to introduce fuel cells as a replacement for batteries that have more application on a daily basis. However, the concept should be simplified to suit the cognitive level of children in primary schools. Moreover, introducing fuel cell technology is also a good example to demonstrate the relationship between each STEM subject.

Fuel Cell as a STEM Related Discipline

Science and mathematics are the core of innovation and development. They are also important subjects for early school age children (Shahali et al., 2017). Science has a major influence towards technology and engineering. We summarise the relationship of each STEM discipline in Figure 4. According to past studies (Hashim, 2018; Hashimah & Yakob, 2018), science can explain phenomenon. Scientific (biology, chemistry, and physics) knowledge also helps to develop new technologies for better human civilization and daily activities. Engineering helps to design and develop high technology for the sake of purposes (Mohd Shahali et al., 2018; Mohd Shahali et al., 2016). While mathematical knowledge is needed to analyse and calculate those scientific data (Leung, 2019; Shafia, 2018). STEM education has been implemented to ensure student are able to make connections and are able to practice STEM skills (science explore; innovation of engineering with technology use; and analytical mathematics) to understand phenomena and solve problems (Rahman et al., 2020). There is a wide range of disciplines and fuel cell technology is one of the emerging disciplines that has a high potential towards a better green ecosystem.

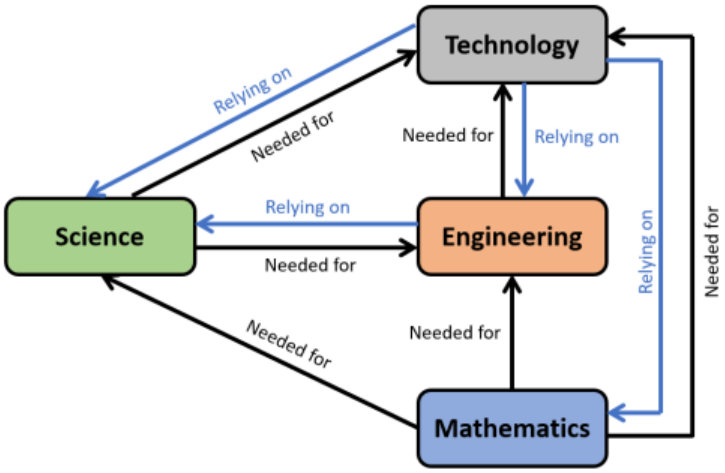

Figure 4: The relationship of each STEM discipline.

Fuel cell technology is a field emerging from the integration of STEM disciplines. This discipline requires each individual STEM discipline concepts and knowledge to develop a functional fuel cell device. Generating power by using hydrogen gas require scientific knowledge. The set of STEM concepts are applied to ensure the process from extracting hydrogen through electrolysis, designing fuel cells to electrical generation. Hence, the entire process needs to be done scientifically. There is a lack of discussion mentioning the relationship between STEM disciplines for fuel cell technology. However, by looking at studies on fundamental hydrogen technology and fuel cell technology (O'Hayre et al., 2016; Santhanam et al., 2018; Wan Daud et al., 2017), this relationship exists. Towards this, we summarised that STEM related disciplines that associated with fuel cell technology involve source identification (science knowledge); apparatus and tools needed (technology knowledge); scientific design (engineering knowledge); and performance measurement (mathematics knowledge).

All STEM knowledge and concepts are interrelated. To ensure the process, scientific knowledge is required in which the facts on general characteristic physical properties and the use of hydrogen and oxygen molecules (Santhanam et al., 2018) are explained. Technology knowledge plays its role when it comes to extracting hydrogen mostly from water sources. Technology allows hydrogen to be extracted and stored using specific tools and equipment. Engineering knowledge later takes part when designing fuel cells. Each component of a

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fuel cell is built from scientific knowledge, in which electrodes (anode and cathode) are needed to allow the oxidation and reduction processes; where the hydrogen and oxygen flow should be placed; polymer electrolyte membrane (PEM) allows positively charged ions to pass through; and calculation of the electrical fuel cell performance via the hydrogen and oxygen supply, air usage, and water output purposely to generate high power. Table 1 summarise the relationship of STEM disciplines in fuel cell technology.

Table 1: The relationship of STEM related disciplines in fuel cell technology.

STEM field	STEM Elements	Description
Fuel Cell Technology (E.g.: PEM fuel cell)	Science	• Scientific facts regarding hydrogen and oxygen gas molecules to be used as the main source for fuel cell. • Chemical reactions between hydrogen and oxygen towards power generation.
	Technology	• Electrolysis requires laboratory apparatus and tools to extract hydrogen gas from water (one of the largest renewal resources). • Hydrogen storage after extraction through the electrolysis process.
	Engineering	• The internal structural design of fuel cells requires scientific facts for better functional and performances. • Fuel cells require basic configuration involving bipolar plates; electrodes (cathode and anode); and polymer electrolyte membranes, PEM (catalyst)
	Mathematics	• Involving calculation to measure hydrogen and oxygen flow, voltage (kW), and efficiency (%).

It is a complex scientific fact to understand how fuel cell works. Since this field only is only taught at the tertiary level, it is important that the basic concepts are introduced at an early age. Obviously, fuel cell technology mostly relates to primary level science subjects. However, primary school children learn each STEM subject as separate subjects. The most difficult situation for teachers is to make sure students know how to use each STEM subject in real world applications. Since fuel cell technology requires the set of STEM knowledge, we suggest that it is best to introduce basic fuel cell devices, how they work, and the supply sources to children at an early age. Their level of curiosity to explore new things will help improve and enhance their scientific skills.

FUEL CELL IN THE PRIMARY CURRICULUM

There are still few studies addressing fuel cells for primary level children. Somehow European textbooks also rarely provide information on fuel cells in their curriculum at an early age. However, fuel cell technology is an advanced scientific concept and application that children should know after they enter tertiary level education in STEM related course. However, children still need to know the basic on how these thing works. The Malaysian curriculum delivers primary level STEM education through *Kurikulum Standard Sekolah Rendah* (KSSR). It is categorised into stage 1 (standard 1-3) and stage 2 (standard 4-6) (Lay & Kamisah, 2018). The STEM textbook for stage 1 is *Matematik* (Mathematics) and *Dunia Sains dan Teknologi* (World of Science and Technology) while stage 2 uses *Matematik* (Mathematics), *Sains* (Science), and *Teknologi Maklumat dan Komunikasi* (Information Technology and Communication). Table 2 demonstrates the learning objectives towards STEM education for stage 2 (standard 4-6; 10-12 years old).

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Table 2: Summary of STEM learning objectives associated with fuel cell technology in the Malaysian school curriculum (Hasran et al., 2019).

Age	Learning objective
Standard 4 (10 years old)	• Develop project based on non-metal material with electrical circuit. • Explaining the importance of innovative new technologies for a better well-being.
Standard 5 (11 years old)	• Develop project based on metal material with electrical circuits. • Explaining the variety of natural resources in daily life. • Understanding the differences between non-renewable energy and renewable energy.
Standard 6 (12 years old)	• Develop a project based on non-metal, metal, and electrochemistry. • Designing models for complex machine by applying scientific concepts such as electricity, acceleration, and light.

Our review of recent STEM textbooks (2017 revised) found that, the only basic knowledge children would have that can be associated with fuel cell technology is through *KSSR Sains* (Science) Standard 4 and Standard 5. Those related topics are Energy (from KSSR Science Standard 4) (Figure 5) and Electric (from KSSR Science Standard 5) (Figure 6). It shows that children are only being exposed to prior knowledge on energy and electricity at the age of 10 years old. For topic of energy, children are exposed to energy resources (non-renewable energy resources and renewable energy resources), types of energy and energy conversion (Anwar et al., 2019). While the electricity topic exposes children to the electrical energy resources, basic electrical components, types of circuit, bulb brightness, effects of negligence and precautionary steps while dealing with electricity (Abd Karim et al., 2020). Here we can see that children learn the basics of renewable energy but are not introduced to hydrogen energy. However, by knowing that water is one of type of renewable energy, it can be extended that water can be used to obtain hydrogen gas. On the other hand, the dry cell concept is almost similar to the fuel cell concepts but is only limited to small and domestic usage, while fuel cells are more oriented towards big applications.

Figure 5: Energy topics in Malaysian KSSR Science standard 4 (Anwar et al., 2019).

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Figure 6: Electric topic in Malaysian KSSR Science standard 5 (Abd Karim et al., 2020).

These prior knowledges (energy and electricity) are the foundation for fuel cell technology knowledge and can be formulated and simplified to suit children's cognitive level. However, further studies should be conducted to ensure that the fuel cell concept can be learned by children. Meanwhile, we suggest that the fuel cell concept at this level of age should focus on several concepts as in Table 3. Basic fuel cell functions might be hard to understand by children verbally and with demonstrations. However, digital games can play a role to illustrate this concept into game mechanics. Designing the fuel cell concept into game mechanics will allow children to explore and learn the concept. Trial and error in a fun environment help knowledge construction on how a fuel cell works.

Table 3: Suitable basic fuel cell concept for children at the primary level.

Item	Description
What is a fuel cell and what is its function?	• A device that generates electricity
What is the main source for fuel cells?	• Hydrogen gas (needs to be extracted from water)
What is the structure of a fuel cell?	• PEM, anode and cathode, flow field channel
How do fuel cell work?	• Hydrogen flows into the fuel cell along with oxygen from the air. • Hydrogen discharges into ions (positive and negative) and pass through a PEM. • Negative ions flow to generate electricity while positive ions combine with oxygen and produce water that flows from the fuel cell.

INTEGRATING FUEL CELLS INTO A GAME

The number of studies integrating the fuel cell technology concept into a game is limited. Almost no available studies investigate how fuel cells are gamified into a game mechanics especially for children. There is a study conducted to explore the acceptance of secondary students to learn more on fuel cells. The descriptive data shows that more than 78.6% of secondary students did not know what a fuel cell is, the use of fuel cells and their benefits, while 72.5% are willing to know more about fuel cells (Hasran et al., 2019). A study conducted by Hasran et al. (2019) indicates that children transitioning into secondary level have the intension and the curiosity to know more about fuel cells. However, they did not experience or were not exposed to fuel cells

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either in books, classrooms, or school STEM programs. In fact, Malaysian STEM education still does not include fuel cells in the curriculum.

Reflecting on the data, students are willing to learn about fuel cells. If fuel cell material is carefully design ed to match the cognitive level of children at early age, they can be exposed to the fuel cell concept. Games also acts as a new television (entertainment source) where children gather information while being in a gaming world. Games integrating useful STEM related content can help children relate their prior knowledge of STEM while playing games. This pedagogical approach has a high tendency to influence children STEM cognitive ability and perhaps stimulate their interest to pursue STEM careers in the future (Ishak et al., 2021b; Kukulska-Hulme, 2021).

Integrating the fuel cell concept into a game must be applied through gamification. Gamification allows the integration of concepts into game mechanics (Al-Azawi et al., 2016; Rosly & Khalid, 2017; Tan, 2016). Integrating concepts into other game elements allows children to experience a STEM learning environment that is associated with fuel cell technology. Here arises the crucial question of how to create a fuel cell game for children. As children have limited cognitive abilities, putting too much fuel cell concepts might make the game hard to play and they will easily lose interest to play. On top of that, they is no single recipe to make a good educational game, particularly STEM games (Kalmpourtzis, 2019). Most designs rely on several guidelines which might only work for certain games. Game designers should pay attention when designing STEM-based digital games.

STEM digital games that use fuel cell learning concepts require teamwork (production team) (Rosly & Khalid, 2017; Tan, 2016). The collaboration of game designers, fuel cell experts, STEM teachers, and game programmers will lead to a successful game development. To ensure a fuel cell game achieve its developmental goal, the game should pay more attention on the design input. The game should not only rely on a model from a game design perspective. It should combine both a game design perspective and an educational technology perspective. The UDIN model is a suitable universal framework to be used as guidelines for any digital learning product (Din, 2016, 2020; Lubis et al., 2015) (Figure 7). Applying the STEM digital game context, studies (Ishak et al., 2021a, 2021b) were conducted to extend the UDin model to an educational digital game perspective (Figure 8). They suggest that any STEM based digital game should consist of input specification on leaning theories; pedagogy; learning strategies; STEM learning content; and game elements. Also, some study on children media suggest that the principle game design for children is the essential aspect (Fisher, 2015).

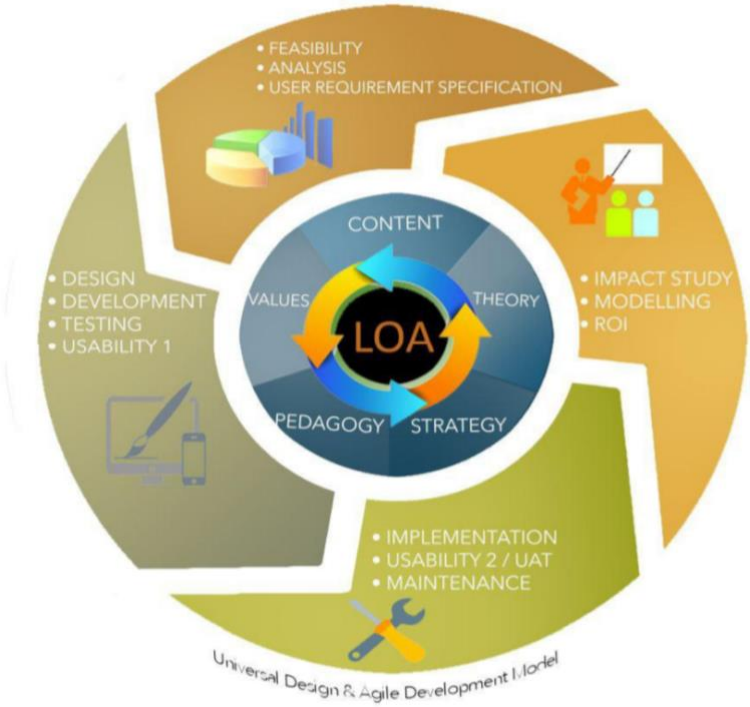

Figure 7: UDin Model for universal digital product design and development (Din, 2020).

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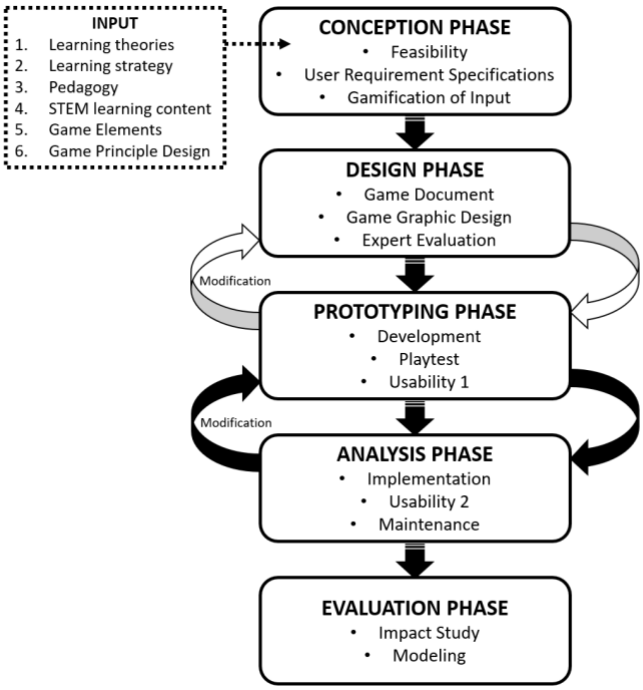

Figure 8: Universal STEM digital game design and development (Ishak et al., 2021a, 2021b).

THE WAY FORWARD AND FUTURE PERSPECTIVE

Based on the evidence from existing supportive literature, our argument on the possibility of exposing fuel cell technology through a digital game to primary level children is literally suitable. However, our argument needs further research and there are still several aspects that need to be looked through and proven. The most important one is on the fuel cell content itself. A feasibility study on the fuel content, specifically for children around 10-12 years old, should be conducted. The content should undergo several validation processes and cross checks with STEM teachers, fuel cell experts and lastly the children's acceptance and the game's suitability should be evaluated. After such data is gathered, it will be easier for a game designer to design an interactive fuel cell based digital game specifically for children. An entertaining and engaging game design will be a key success for the game. But aspects of input specification and creativity should be blended. The fuel cell-based STEM game will undergo several tests to ensure it fits the need and it can be improved to achieve the learning outcomes. The game should not solely be fun. Hence, we propose a causal effect conceptual framework to illustrate our argument (Figure 9).

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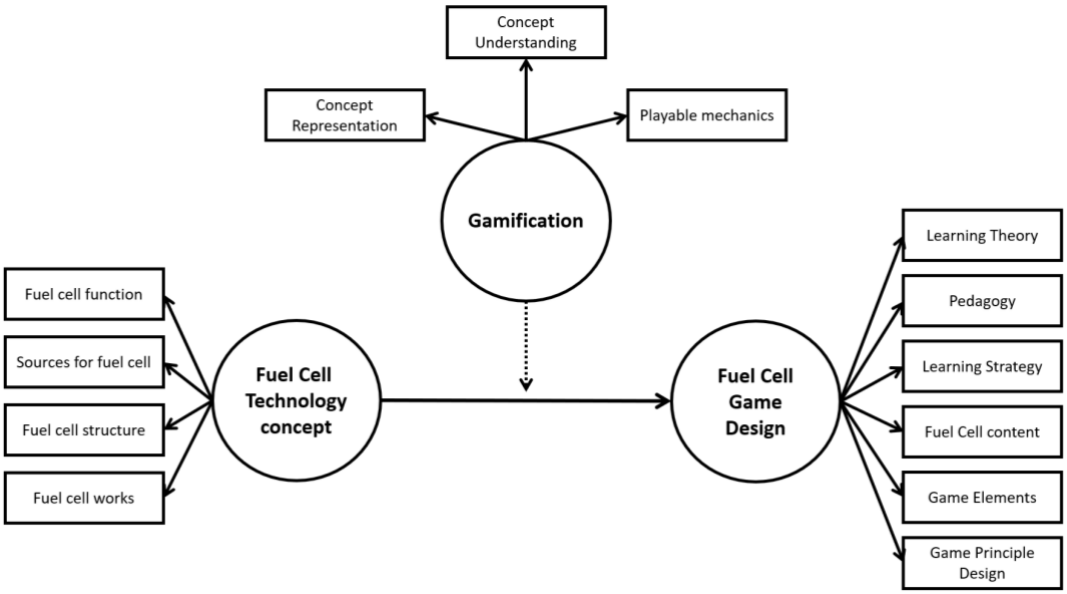

Figure 9: Proposed conceptual framework to explain how fuel cell technology could be integrate into a digital game.

CONCLUSION

As a conclusion, the idea of using a digital platform to expose children to fuel cell technology is still limited and needs further collaboration among fuel cell experts and science teachers. However, there are a few possible potentials to promote the fuel cell technological concept. We prepared the comprehensive justification through this conceptual paper. We conclude that the fuel cell concept can be presented to children since they have prior knowledge of energy and electricity. By relying on game mechanics, a well-designed fuel cell-based STEM digital game will allow children to explore the integrated learning concept and construct knowledge (declarative knowledge). This fundamental study serves to benefit fuel cell education and planning for fuel cell industries. On top of that, this initiative will sustain children's interests for further study and pursue STEM careers especially related to fuel cell technology in the future.

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