Students as Digital Game Designers: Addressing the 21st Century Chemistry Education Needs in Malaysia

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Abstract

In order to meet the challenges in the global economy market of the 21st century, Malaysia needs to produce students who master both the knowledge of chemistry and 21st century skills. Chemistry is one of the important branches of science. However, chemistry is perceived as a difficult and unpopular subject due to the abstract nature of chemical concepts. The purpose of this paper is to propose an instructional approach that emphasizes simultaneously on enhancing conceptual understanding and developing the 21st century skills. Many studies have reported that digital game-based learning can provide positive impact on students' learning. Commercial and educational digital games have been developed for classroom integration. However, there are many obstacles to implementing the students as game consumers approach in the educational settings. One alternative approach offered by some researchers is to allow students to take on the role of game designers, developing digital games during teaching and learning process. It is believed that this approach can create a platform that allows students to deepen subject content knowledge, and practice various 21st century skills in real situations. Based on this approach, a module known as MyKimDG has been developed. This paper also demonstrate a brief lesson in MyKimDG to the teaching and learning of a specific unit in the Malaysian Chemistry Curriculum.

Keywords: chemistry learning, constructivism, constructionism, and learning through designing.

Introduction

Malaysia needs to produce students who are competent in the field of science and technology (S&T), and hence capable of generating S&T innovation to contribute to the well-being of mankind as well as to trigger the country's economic growth. To become competent in the field of S&T, students must be STEM (Science, Technology, Engineering and Mathematics) literate and have mastery of the 21st century skills.

STEM literate students must have master the knowledge of chemistry because knowledge of chemistry applied across most of the fields of S&T (Balaban and Klein, 2006). Indeed chemistry is often called the central science (Brown et al., 2011; Chang, 2007). According to Risch (2010), the knowledge of chemistry is the foundation for innovation, scientific literacy and most notably problem solving in connection with sustainable development. With chemistry knowledge, materials can be designed to solve various problems in everyday life. In the 21st century, chemistry will continue to play a leading role in the field of S&T and contribute towards solving the problems of human life.

Apart from knowledge, innovation in the 21st century requires a new range of skills known as 21st century skills. For example, innovation in today's world is driven by the formation of networks with multiple parties including experts and researchers with related interests as well as consumers and customers. The 21st century skills enable one to communicate and collaborate effectively with various parties.

In short, students who are competent in the field of S&T must master both the knowledge of chemistry and the 21stcentury skills. Therefore, chemistry education in Malaysia in the 21st century should be given simultaneously on integration of knowledge acquisition and nurturing of 21st century skills to ensure that students are equipped with knowledge, skills and values that are relevant to the current needs so that they can adapt themselves to the 21st century work and social environments.

Chemistry Education in Malaysia

In the early 1960s, students at upper secondary level learn science based on the syllabus by the Cambridge Examination Syndicate. In 1972, Modern Chemistry subject was introduced at upper secondary level. The syllabus was adapted from the Nuffield Chemistry 'O' level course.

In 1989, an indigenous form of curriculum that best suit the national context, known as the Integrated Curriculum for Secondary School (KBSM), was implemented in Malaysian secondary schools. The Malaysian Science Curriculum was developed based on the National Education Philosophy, National Science Education Philosophy and taking into consideration the vision and mission of the national and global challenges.

Chemistry is one of the elective science subjects in the Malaysian Science Curriculum offered at the upper secondary level. The Chemistry curriculum has been designed not only to provide opportunities for students to acquire chemistry knowledge and skills, develop thinking skills and thinking strategies, and to apply this knowledge and skills in everyday life, but also to inculcate in them noble values and the spirit of patriotism (Bahagian Pembangunan Kurikulum, 2012).

In line with the current global changes in the 21st century as well as the national vision and mission, Malaysia has concentrated its efforts to produce students who are equipped with the knowledge, skills, and values that need to be mastered to succeed in life and careers in the 21st century. Starting in 2011, the national curriculum is giving greater emphasis on Higher Order Thinking Skills (HOTS), and various 21st century skills such as reasoning, creativity and innovation, entrepreneurship, and information and communication technology (ICT). Thus, in teaching and learning, teachers need to emphasise the mastery of those skills together with the acquisition of knowledge and the inculcation of noble values and scientific attitudes.

Digital Games and Chemistry Learning

Chemistry is usually considered difficult. The abstract nature of many chemical concepts is one of the key factors that cause difficulty in learning chemistry. While the literature is replete with studies and papers, which investigate students' understanding of chemical concepts and suggest potential remedies, fewer studies focus simultaneously on enhancing conceptual understanding and developing the 21st century skills. Hence, educators should be encouraged to design innovative and effective learning strategies to enhance both conceptual understanding and 21st century skills development. In this case, a change in chemistry teaching and learning (T&L) practices is critical. This is especially more crucial when dealing with today's students who are 'native speakers' (Prensky, 2001) of the digital language of computers, digital games and the internet. The T&L practices must meet the needs of these digital natives and subsequently achieve the desired aspiration.

One approach suggested by researchers to educate the digital native generation is the integration of digital games in the T&L processes as digital game is a medium favoured by students. In Malaysia, Rubijesmin (2007) showed that 92.1% of students involved in the study were familiar with digital games. After several years, Lay and Kamisah (2015) revealed that the percentage has increased to 98.8%, and 21.8% of them used at least 3 hours per day for playing digital games. Nowadays, the integration of digital games in learning or digital game-based learning (DGBL) is gaining popularity parallel with their popular reputation among students (Kamisah and Aini, 2013). Many studies have reported that DGBL can provide positive impact on students' learning. In general, the studies on DGBL were carried out through two approaches, namely (1) student as game consumer or player, and (2) student as game designer.

In the first approach, the students were involved in playing digital games developed by educators or commercial digital games in the market. However, there are many obstacles to implementing the student as game consumer approach. For instance, the contents of commercial digital games are inaccurate or incomplete (Van Eck, 2006) and the development of professional educational digital games is time consuming (Hwang et al., 2013). In addition, many digital game players do not play educational digital games as they do not find the game play in these games to be compelling (Pivec, 2009). This happens because educational digital games are designed by academics who do not really understand the art, science and culture of digital game design (Van Eck, 2006). As a result, the product has failed dismally as a game. Prensky (2008) also raised this issue and states '*...the students had no input into its creation, and the stuff came out cute to the adults, but boring to the kids*'. According to Prensky (2008), students even told straight forwardly: '*Don't try to use our technology, you'll only look stupid*.'

One alternative of DGBL approach that has been proposed by some scholars (such as Kafai, 1996; Papert, 1998; Jung and Park, 2009; Kamisah and Aini, 2013) is for students to design their own digital games. Many studies have reported that this approach provide opportunities for students to explore ideas according to their own interests (Kafai & Ching, 1996); become active participants and problem solvers, engage in social interaction by sharing their designs and helping each other, and take ownership of their own learning (Baytak & Land 2010); acquire knowledge of programming (Kafai et al., 1997); as well as develop ICT literacy to produce new things and develop new ways of thinking based on the use of ICT tools (Kafai, 2006). Digital game design activities also open the door for young digital game players to become producers of digital games (Kafai, 2006). In addition, Vos, van der Meijden and Denessen (2011) has reported that this approach is a better way to increase student motivation and deep learning compared to the student as game consumer approach. In Malaysia, Yusoff (2013) also found that this approach can enhance students' knowledge in addition to creating a fun environment. In short, the student as game designer approach can enhance deep learning and provide a platform for students to develop the 21st century skills.

Therefore, we have initiated an innovation approach which involves students as digital game designers while learning chemistry to deepen their understanding in chemical concepts, and practice various 21st century skills. Students are expected to apply concepts learned in the course as well as ICT skills to collaboratively design digital games.

Learning Theories

The student as game designer approach is inspired by two important theories in learning and education which are constructivism and constructionism (Resnick, 2003).

1. Constructivism

According to constructivist theory of learning, learner is knowledge builder. Learner does not receive knowledge passively, but he/she interpret the knowledge received and then modify the knowledge in a form that acceptable to him/her. In other words, individual learner actively constructs new knowledge pursuant to his/her existing knowledge. Construction of new knowledge can be improved through social interaction. Vygotsky (1978) gave important to the role of social interaction in learning and cognitive development. He believed that collaboration between learner and teacher or more skilful peers will provide scaffolding to learner within the Zone of Proximal Development to construct new knowledge. However, no interaction would be beneficial if the new information is presented to students traditionally. Instead, students should be given the opportunity to explore the new knowledge. Bruner (1966) believed that learning and problem solving emerged out of exploration of new knowledge.

2. Constructionism

The theory of constructionism is built on the theory of constructivism which defines learning as knowledge construction in the student's mind. In addition to the constructivist theory, constructionist theory of learning asserts that the construction of new knowledge happen felicitously in a context where students are consciously involved in the production of external and sharable artefacts (Papert 1991). This theory goes beyond the idea of learning-by-doing as indicated by Papert (1999a) that '*I have adapted the word constructionism to refer to everything that has to do with making things and especially to do with learning by making, an idea that includes but goes far beyond the idea of learning by doing*'. Indeed, Papertian constructionism challenges the learner applying the knowledge being explored to construct more complex ideas or larger theory. This theory emphasizes the role of design (making, building or programming) (Kafai and Resnick, 1996) and external objects (Egenfeldt-Nielsen, 2006) in facilitating the knowledge construction. In this process, the designers (or learners) create artefacts which are significant to themselves based on their interests, learning styles and their experience, and shares their artefacts as well as the artefacts' designing process with others.

Computers play a role in the constructionist learning theory. Computers can be used as a building material (Papert, 1999a). The idea of using the computer as a construction material submitted by Papert is very different from the idea of using the computer as a tutor, tool and tutee put forward by Taylor (1980). For Papert and Franz (1988), a computer is a 'material to be messed about with'. Learning occurs when learners are 'messing about' with the computer. The introduction of computers is also able to change the context of learning (Papert, 1991). Computers can serve as a convivial tool (Falbel, 1991). The willingness of learners to learn will increase because they can use the computer in building artefacts (Papert, 1991). Papert (1980) has described that '*The computer is the Proteus of machines. Its essence is its universality, its power to simulate. Because it can take on a thousand forms and can serve a thousand functions, it can appeal to a thousand tastes*'. However, he stressed that the main focus is not on the computer but on the minds of students (Papert, 1980).

Additionally, constructionist theory also values the diversity of learners and social aspects of learning. According to Kafai and Resnick (1996), this theory recognizes that learners can build relationship with knowledge through various ways, and community members can act as collaborators, coaches, audiences and co-constructors of knowledge in the constructionist learning environment.

Both constructivist and constructionist theories imply that learning depends on the learners themselves and learning can be enhanced through social interaction and discovery. Additionally, constructionist theory suggests that learning can be further enhanced if learners are involved in collaborative artefact designing projects using ICT as construction material.

Conceptual Framework of MyKimDG

Based on constructivist and constructionist theories, a module known as Malaysian *Kimia* Digital-Game (MyKimDG) has been developed as a mechanism for enhancing conceptual understanding and developing the 21st century skills. The conceptual framework of this study is summarized in Fig. 1.

1. Learning Approach

Learning approaches such as collaborative learning, discovery learning and learning through designing digital game (student as game designer) are integrated in MyKimDG.

Collaborative Learning. Activities in MyKimDG are designed so that students engage in discussion, share and exchange ideas in groups. Through this approach, triggering of cognitive conflict and restructuring of ideas will occur when students share their ideas from their own perspective. It also improves students' 21st century skills such as collaboration, communication and interpersonal skill because students are able to practice in the real world.

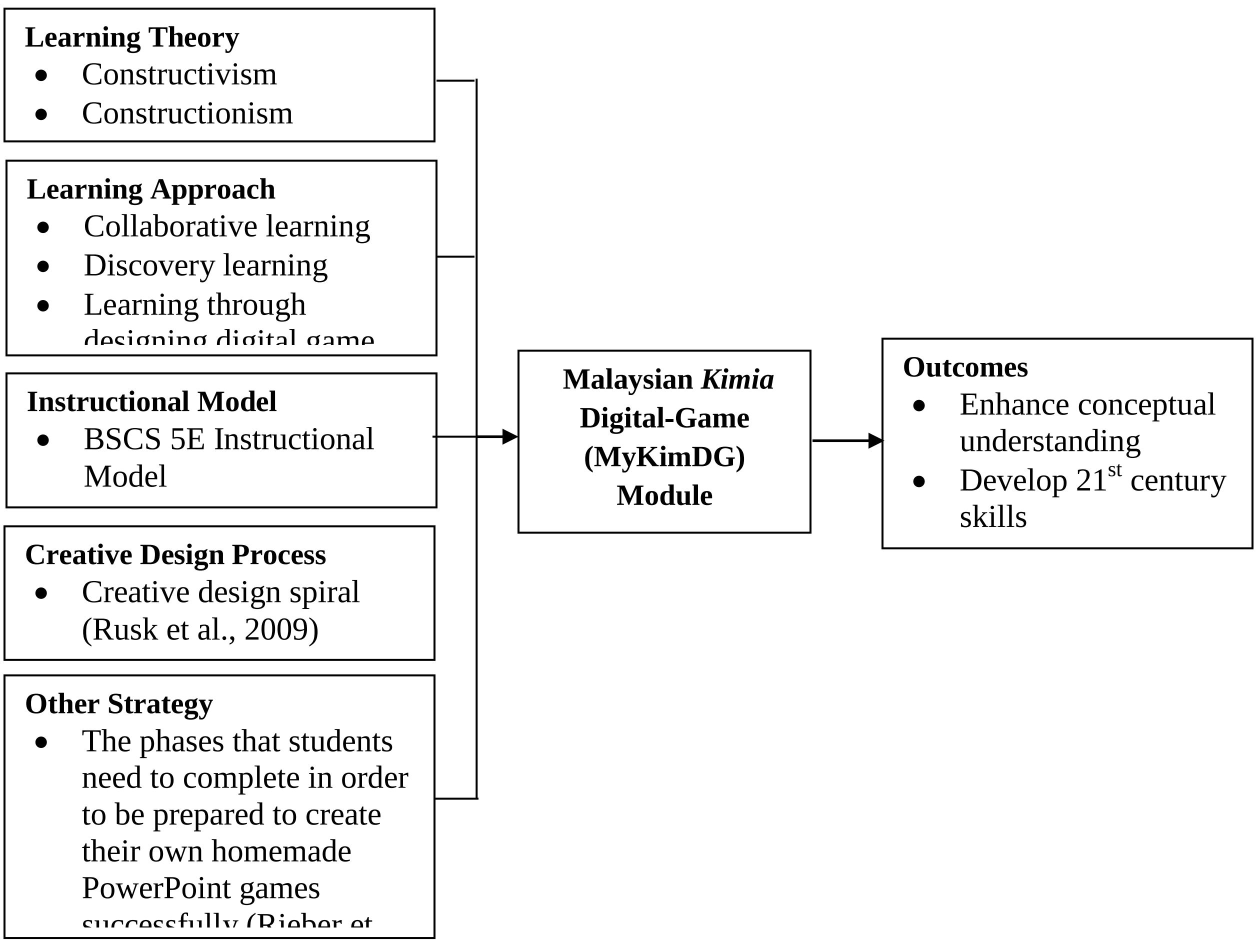

Fig. 1 Conceptual framework of study

Discovery Learning. Students are guided towards exploring chemical concepts. Students will gain deeper understanding when they are given opportunities to discover new concepts for themselves. It also lets students acquiring problem-solving skill, experiencing the exploration and discovery activities, and stimulating their own thinking. As students embark on the discovery process, teacher reminds them of the important of the process in learning. If they can perceive the values of the process, they will be motivated to learn chemistry. In this approach, students are empowered to take responsibility for their own learning and practice the 21st century skills in real situations.

Learning through Designing Digital Game. In MyKimDG, students are involved in designing PowerPoint games related to chemical concepts. They discuss in groups and apply the concepts learned to design PowerPoint games. With this, students can visualize the concepts in the sub-microscopic level.

PowerPoint game is selected as Microsoft PowerPoint software is available at all schools and the use of the software does not involve additional cost and complicated programming languages. The only technical skill that students need to master to design PowerPoint games is how to create custom animations. In addition, existing PowerPoint game templates are available online and can be modified by students to help them progressively master the game designing skills. This strategy is parallel with the development phases proposed by Rieber, Barbour, Thomas and Rauscher (2008). However, students are also encouraged to use other software like *Game Maker* and programming languages such as *Java*, *Logo* and *Scratch* if they are skilled in the software.

When students carry out their digital game designing project, they are guided to move through the creative design spiral (Rusk et al., 2009) in order to help them develop new ideas. Students are also given the autonomy to choose their own game design, plan and carry out the project based on the group's consensus. The students are also told that the PowerPoint game will be used to help their peers who face difficulty in learning the chapter. It is expected that this strategy will improve students' perceived competency, autonomy and relatedness, and hence increase their motivation in chemistry.

The learning through designing approach aims to deepen students' conceptual understanding in chemistry as cognitive conflict may be triggered during activities and hence, new understanding may discover. As the same time, it provides a platform for students to develop the 21st century skills.

2. Instructional Model and Strategy

Studies have revealed that mastery of science concepts will be enhanced if students become aware of their misconception. To help students realize their misconception and replaced it with scientifically acceptable concept (i.e. conceptual change), cognitive conflict strategy has been proposed by scholars such as Piaget (1977) and Posner, Strike, Hewson and Gertzog (1982). Therefore, the BSCS 5E Instructional Model (Bybee et al., 2006) designed to facilitate conceptual change is applied in MyKimDG.

To help students understand the chemical concepts, students are guided to explain macroscopic experience at the sub-microscopic and symbolic levels. It is known that conceptual understanding in chemistry involves making use of three main representations or levels. The triplet relationship is the key model in chemical education (Gilbert & Treagust 2009).

In this study, the phases of the BSCS 5E Instructional Model and Creative Design Spiral have been modified and standardized. The resultant phases are Inquiry, Discover, Produce, Communicate and Review. Table 1 shows the phases in MyKimDG, and related phases of the BSCS 5E Instructional Model and Creative Design Spiral.

Table 1. Phases in MyKimDG and related phases of the BSCS 5E Instructional Model and Creative Design Spiral

MyKimDG	BSCS 5E Instructional Model	Creative Design Spiral
Inquiry	Engage	Imagine
Discover	Explore	Experiment
Produce	Elaborate	Create
Communicate	Explain	Share
Review	Evaluate	Reflect

During implementation of MyKimDG, students are guided to experience and realise the phases. As the process is done repeatedly, new ideas are always generated and students' 21st century skills such as inventive thinking skills are developed. Students are expected to practice the process in everyday life and in the workplace.

Apart from that, it is expected that the acronym IDPCR can help students remember the five important clusters of 21st century skills which need to be integrated in the Malaysian science curriculum, i.e. Inventive thinking, Digital-age literacy, high Productivity, effective Communication and spiritual values (*nilai Rohani*). The five clusters of 21st century skills have been identified by Kamisah and Neelavany (2010). Table 2 showed the outline of instructional activities in MyKimDG.

Table 2. Outline of Instructional Activities in MyKimDG

Phase	Purpose	Activity
Inquiry *Predict, ask, hypothesize, identify problem, brainstorm*	1. Arouse students' interest 2. Access students' prior knowledge 3. Elicit students' misconceptions 4. Clarify and exchange current conceptions	1. Teacher shows discrepant events. 2. Students make observations and explain the phenomena at the sub-microscopic and symbolic levels. 3. Students discuss in groups and compare their ideas with their peers.
Discover *Investigate, experiment, explore*	1. Expose to conflicting situations 2. Modify current conceptions and develop new conceptions 3. Provide opportunities for students to demonstrate their conceptual understanding, and skills	1. Students perform hands-on and minds-on activities in groups. 2. Students are encouraged to engage in discussions and information seeking using ICT. 3. Students generate explanation of the observed phenomenon. 4. Students practise the skills needed in an experiment or activity. 5. Students are asked to communicate in groups and report back with their findings.
Produce *Create, construct, invent, build, design, tinker, elaborate*	1. Challenge and deepen students' conceptual understanding and skills 2. Provide additional time and experiences that contribute to the generation of new understanding	1. Students apply their new ideas by conducting additional activities 2. Students perform additional tasks that are more complex and involve HOTS. 3. Students carry out open-ended projects. 4. Students create digital games.
Communicate *Explain, share, discuss with peers, ask an expert, defend*	1. Provide opportunities for students to share their new understanding and skills 2. Provide opportunities for students to exchange their new understanding	1. Students report back with their new ideas and skills. 2. Students also listen to input from peers and defend their ideas. Peer's input may guide them towards deeper level of understanding. 3. Students compare their ideas with the

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		teacher's explanations.
Review *Check, evaluate, reflect, improve, repair*	1. Students assess their understanding, skills and competencies 2. Students think creatively for the purpose of improvement 3. Teachers evaluate student progress toward achieving the learning outcomes	1. Students reflect upon the extent to which their understanding, abilities and competencies have changed. 2. Students improve their ideas or skills based on reflection or input from peers. 3. Teacher conducts a test to determine the level of understanding of each student.

Implementation of MyKimDG

In the following section, the authors present a brief lesson in MyKimDG to the teaching and learning of a specific unit (i.e. preparation of insoluble salts) in the Malaysian Chemistry Curriculum which involved precipitation reaction.

Inquiry

1. Teacher demonstrates two reactions that may be used to prepare lead(II) sulphate:

	Reaction	***Observation***	***Chemical equation***
A	Lead(II) nitrate solution + sodium sulphate solution		
B	Excess solid lead(II) carbonate + dilute sulphuric acid		

2. Students record the observations and write the chemical equations involved.
3. Students describe how to obtain lead(II) sulphate from the mixture in Reaction A and B.
   (a) Draw the set-up of the apparatus is involved.
   (b) In your opinion, which reaction is more appropriate to prepare insoluble salts such as lead(II) sulphate? Explain your answer.
4. Students make a conclusion about the appropriate reaction to prepare insoluble salts.
5. Students share their findings with other groups.
6. Students are asked to explain the strategy used, i.e. inquiry-discovery.

Discover

1. Students plan experiments to prepare lead(II) iodide and silver chloride in group.
   (a) Discuss the materials needed to prepare lead (II) iodide and silver chloride.
   (b) Write the chemical equations involved.
   (c) Plan the procedures for experiment by constructing flowchart.
2. Students carry out experiment to prepare lead(II) iodide and silver chloride.
3. Students generate explanation of each phenomenon.
4. Students are asked to report back with their findings.

Produce

1. Students play a game related to the precipitation reactions involved in the preparation of insoluble salts.

2. Students are asked to differentiate between a good game and a bad game.
3. Students are asked to improve the game to make it more educational and entertaining following phases of IDPCR, in order to help their peers who face difficulty in learning the concept.
4. Students are told that they may commercial their innovative product to benefit financially.
5. Students are reminded to apply 21st century skills during the project.

Communicate

1. Students share their digital games with other science or chemistry educators.
2. Students improve their digital games.

Review

1. Students plan and carry out experiments to prepare lead(II) chromate and barium sulphate in group.
2. Students write the chemical and ionic equation involved.
3. Students reflect upon the extent to which their understanding, abilities and competencies have changed.

Conclusion

In this study, collaborative learning, discovery learning and learning through designing digital game are integrated in the MyKimDG. The learning approaches will create supportive learning environments for student to learn chemical concepts meaningfully. Most importantly, MyKimDG allows students to practice the 21st century skills in real situations. In conclusion, the implementation of MyKimDG can help improve students' achievement in chemistry and their 21st century skills.

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