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STEM-21CS Module: Fostering 21st Century Skills through Integrated STEM

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Abstract

Malaysia calls for a society that is highly knowledgeable in the field of Science, Technology, Engineering, and Mathematics (STEM) and equipped with 21st century skills to provide professional workforce that can compete globally. The application of a STEM interdisciplinary approach and teaching and learning (T&L) strategies such as problem-based and inquiry-based learning are proposed in development of the STEM-21CS Module in order to foster 21st century skills in the existing science curricula. A majority of real-world issues today are interdisciplinary in which they require students to comprehend the need to integrate multiple disciplines to solve them. STEM-21CS Module allows students to master scientific knowledge and subsequently master other disciplinary skills. It is aimed at improving students' abilities to enrich their knowledge through hands-on and minds-on activities. The field of engineering requires the knowledge of product design and inventive problem solving skills. The integration of information technology in T&L is recommended in meeting the current needs of the Net Generation. Besides that, mathematics plays a vital role in providing computational tools, especially in analysing data. The STEM-21CS Module is expected to nurture 21st century skills such as digital era literacy, inventive thinking, effective communication, high productivity, and spiritual and noble values among Malaysian students.

Keywords STEM (Science, Technology, Engineering, Mathematics), interdisciplinary approach, constructivism, constructionism, 21st century skills

Introduction

The shift in this current world economy from a manufacturing-based to knowledge-based economy, scientific innovation, augmented globalisation and advances in communication and information technology (ICT) have changed the job market in this modernised era. Our country is in need of knowledgeable human capital in order to generate innovative thinking to remain competitive globally. The generation of innovation in science and technology (S&T) has been an important key towards the country's effort in becoming a fully developed nation by the early 21st century (Vision 2020). In efforts to achieve Vision 2020, Malaysia should first produce human capital that is both knowledgeable in the field of STEM and equipped with 21st century skills. The integration of STEM provides opportunities for students to develop and explore technology through a meaningful learning process in real-life context (Johnson, Peter-Burton & Moore, 2016). STEM education is one of the meta-disciplines which integrates knowledge and skills from all four fields: science, technology, engineering and mathematics (Morrison & Bartlett 2009; Morrison 2006) to study the challenges that arise in our world today such as energy shortages and environmental and health problems (Bybee, 2010). Students fully equipped with STEM knowledge are able to identify, apply and integrate its concepts in order to understand complex problems and generate innovative solutions to solve those problems (Chew et al., 2013). Twenty-first century skills are important in preparing students to remain relevant in life and work during this, which undoubtedly are very complex and competitive. (Partnership for 21st Century Skills, 2009; Osman, Abdul Hamid & Hassan, 2009).

Realising the prerequisites of 21st century skills, Malaysia has participated in international assessments such as Trends in International Mathematics and Science Study (TIMSS) and Programme for International Student Assessment (PISA) to assess students' achievements and skills. However, the results achieved by students in TIMSS and PISA were not impressive (IEA, 2012; OECD, 2013). This is due to the lack of efficiency in T&L methods and our current educational system which does not emphasize on higher order thinking skills (HOTS) (Nik Pa, 2014). Moreover, the results also show that the adoption of 21st century skills are lacking in the T&L process. It was identified that students failed to apply their knowledge in using critical thinking skills to solve real-life problems (Kay, 2009; Ministry of Education Malaysia, 2013).

According to Kay (2009) and Rotherham and Willingham (2009), the combination of 21st century skills and content knowledge are equally important and this combination should be applied to students even during their lower secondary level. Students will be more prepared to enter a higher secondary level learning with solid curriculum if these 21st century skills are exposed to them in advance. Moreover, Senechal (2010) found out those countries with higher performance in PISA such as Australia, Canada, Finland, Hong Kong, Japan, Netherlands, New Zealand, South Korea and Switzerland each provides their students with a solid curriculum in terms of its content and the practice of 21st century skills. These countries are well-advanced in the field of STEM. Halim (2013) concluded that STEM education is the perfect medium for the implementation of 21st century skills. This situation indirectly implies that the current educational system should not neglect STEM education, which is capable of fostering 21st century skills and creating a society that is able to compete globally. In relation to that, this paperwork will discuss the conceptual framework underlying the development of the STEM-21CS Module through the application of an interdisciplinary approach and the integration of STEM T&L strategies in order to nurture 21st century skills among students.

Interdisciplinary Approach in STEM-21CS Module

STEM integration functions as a channel in fostering 21st century skills with subject content. The application of a STEM interdisciplinary approach and STEM T&L strategies such as problem-based learning and inquiry-based learning can be applied simultaneously in the integration of STEM. This is to ensure that students will be able to develop meaningful knowledge and learning by themselves as the STEM T&L approaches and strategies connect them with the real world and daily life problems. STEM integration can aid in the improvement of problem-solving skills, critical and analytical thinking in students, which lead them to a better real-world connection in the curriculum (Brophy et al., 2008; Brown et al., 2011; National Science Board, 2007) and most importantly STEM education prepares students to face 21st century global economy challenges (Becker & Park, 2011).

In accordance with the trend of a 21st century education, separation of subjects is less relevant in allowing students to master various knowledge and solving non-routine problems. STEM integration can prevent STEM subjects from being taught separately and discretely as practiced currently in schools. An interdisciplinary approach can be defined as a mode in using methods or knowledge of more than one discipline to analyse an issue, problem, or topic (Jacobs, 1989). Customarily, interdisciplinary education is problem-centred and correlates the knowledge of several disciplines in order to solve complex real-life problems (Nikitina, 2006). All four separate disciplines in STEM are combined into one through an interdisciplinary approach. Cantu (2011) found that this approach can diminish the "silo" teaching effect separately in science, technology, engineering and mathematics. Thus, it allows students' learning experience to be more consistent and relevant compared to the separate delivery of concepts in curricula that focus on a single subject (Nordin & Othman, 2008). Apart from that, information obtained from various fields can be combined in an effective way to increase students' understanding, knowledge application, involvement, interest, motivation, problem-solving skills, cooperative learning and 21^{st} century skills (Barlex, 2009; Klein, 2006; Price et al., 2011; Roberts & Cantu, 2012).

Underlying Theories of STEM-21CS Module

The development of the STEM-21CS Module is inspired by two important theories in learning and education: constructivism and constructionism. Constructivist theory is an active process whereby students develop the knowledge themselves based on existing knowledge, then re-invent the knowledge in a form that is easily acceptable to them. In other words, new knowledge is formed as a result of the interaction between new information and existing belief or knowledge. If students discover knowledge and the relationships on their own, they will gain a deeper understanding (Bruner, 1962). This theory also suggests that learning happens through social interaction and discovery (Vygotsky, 1978). On the other hand, constructionism theory suggests that the most efficient way to implement the theory of constructivism is to involve students in designing external objects. Constructionism theory insists that the construction of new ideas occurs successfully if students are involved in the production of artefacts in the real world (Papert, 1991).

Both of these theories imply that learning is highly dependent on the students themselves and the learning process can be enhanced through social interaction. Hence, teachers should take into consideration students' existing knowledge and experience as well as provide opportunities for them to build new knowledge. Teachers are incapable of controlling students' learning process directly; however, they can aid them to plan activities that require the students to discuss, share and exchange ideas, and collaborate within the group. These theories also indicate that learning is enriched through the discovery and construction of external objects. Therefore, teachers should plan activities to guide students in discovering new ideas. The order of the content ought to be presented so that existing knowledge/skills can be appraised whenever new knowledge and/or skills are introduced. Learning through designing is one of the approaches that is based on both theories and can be applied to aid in building new knowledge effectively. These strategies involve collaborative learning, discovery learning and learning through designing. Herewith, students can gain a deep and meaningful understanding of a topic.

STEM-21CS Module Development

In the 21^{st} century, an era of knowledge economy (k-economy) and globalisation, Malaysia must produce students who are literate in science, highly innovative and possess 21^{st} century skills in order to initiate a rapid development of the national economy. Consequently, this study was carried out to improve the current practice of T&L so it can encourage S&T innovation and nurture 21^{st} century skills among students. The STEM-21CS Module is based on the BSCS 5E Instructional Model, which is an acronym for engagement, exploration, explanation, elaboration, and evaluation phases. According to Bybee (2009), each phase in the BSCS 5E Instructional Model helps teachers to balance their teaching and students to have a better understanding of science skills and scientific knowledge. Apart from that, teachers can also combine this model with various other T&L strategies. Thus, the BSCS 5E Instructional Model is used and combined with other T&L STEM strategies to draft T&L plans in the STEM-21CS Module.

The STEM-21CS Module was developed in a Dynamic topic in reference to the existing syllabus in Integrated Curriculum for Secondary School Science Form Two whereby science, technology, engineering and mathematics are correlated and taught all together in the entire module. The prerequisite analysis conducted by researchers regarding form two students and science teachers found out that the Dynamic topic is ranked as the second most difficult topic to be mastered by the students. Students are also given exposure with activities in the STEM-21CS Module that require them to become engineers and scientists to solve real-world problems. The objective is to increase students' interest in the jobs listed in STEM field in the future. Table 1 shows an example of activity in STEM-21CS Module. This activity require students to take up an important role as an engineer that applies technology, engineering and mathematics to solve problems related to renewable energy. Students are asked to design and build a watermill as an alternative to generate energy. In order to help students develop ideas, an engineering design model was applied. The engineering design model, the Creative Design Spiral was introduced by Rusk, Resnick and Cooke (2009) to help students complete their design project. In this process, students will discuss the watermill design (imagine), create a watermill (create), test the produced watermill (experiment), share ideas to gain input from other groups (share), make a reflection of the strength and weaknesses of the produced watermill (reflect) and improve the quality of the watermill based on inputs from other groups, reflection, and tests that were conducted (improve). When students are guided to experience the new process in Creative Design Spiral repeatedly, new ideas will continuously form. Figure 1 shows the Creative Design Spiral.

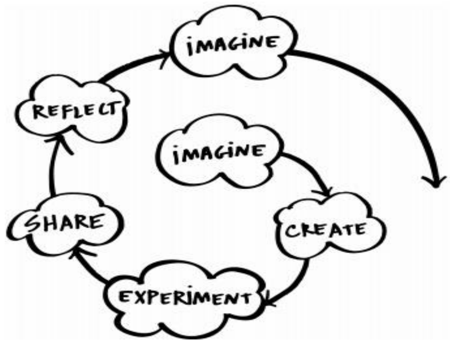

Figure 1. Creative Design Spiral
Source: Rusk et al. (2009)

Table 1. Example of an activity in the STEM-21CS Module

Activity	Power, Work and the Watermill
Time required	Two to three 45 minutes sessions
Group size	4
Learning outcomes	After this activity, students should be able to: • Make a connection between the concepts of power and work and engineering design • Explore nonlinear functions (e.g., power is inversely proportional to time) • Explain the need for using hydropower • Explain how hydropower works
Activity description	In this activity, you are working for H_2O Solutions, an engineering design firm that works mostly with water wheels and water energy! Your city wants to use hydropower instead of fossil fuels to make energy because they are worried about air pollution. The city has hired **you** to design an efficient watermill. The firm (our class) has been split into several engineering teams (student groups). Each engineering team will design and test a slightly different design so that the firm can present the most efficient design to the city. You will calculate power

	and work by measuring force, distance and time for your team-built water wheel.
What do engineers do?	Environmental engineers collaborate with civil, geotechnical, environmental, mechanical and electrical engineers to reduce air pollution problems. They collaborate to design and construct dams that generate electricity from the flow of water. When engineers design these dams, called hydroelectric power plants, they calculate the amount of power that can be generated by the plant. Knowing the dam's potential power generation, they can further estimate the maximum rural or urban region that can be supplied with electricity generated from the dam.
Creative exemplar **(Engage)**	1. Teacher shows video of water wheel that can produce electricity. Video URL: https://www.youtube.com/watch?v=bNltaZ4RE2o 2. Teacher asks several questions to students about the video • What is the water wheel? • How does it work? • Why is the water wheel needed? • How is it used to do work? • What makes it move? 3. Students discuss in groups and compare their ideas with those of their peers.
Your task **(Explore)** ***Remark:** Students are encouraged to collect relevant information from the Internet and other sources	**Scenario: Energy Security Issues** Malaysia still relies heavily on gas and coal for power generation where for Financial Year 2015, gas made up 48.13% of the total energy generated by TNB, followed by coal (40.14%), hydro (11.64%) and distillates (0.09%). A strategic transformation is required urgently to meet the future energy supply. Dependence solely on fossil fuels poses both economic and security risks. (Source: https://www.tnb.com.my/assets/annual_report/2015_annualreport.pdf) Your team challenge is to design an efficient water wheel that can generate power. You need to use your knowledge in science, technology and skills in mathematics to consider the features of a good water wheel. The following guidelines may be useful in helping your group solve the problem: • Imagine what you want to do (how to design an efficient water wheel). • Create a project based on your ideas. • Do the experiment with alternatives.
Explain	• Defend and share your ideas and creations with others (your group will prepare a portfolio for your idea). • Show the real product during the class presentation.
Elaborate	• Reflect on your experiences. • Imagine new ideas and new projects. • You are encouraged to upload your group's design onto YouTube and other social media and be prepared to receive comments from other users.

Evaluate	• Performance based assessment. • A rubric form is used to evaluate the effectiveness of the design in the aspect of power produced by the water wheel, cost, user-friendliness, creativity, environmentally-friendliness, usability, relevance, etc. • Peer-assessment, self-assessment, and teacher assessment.

In addition, the development of the STEM-21CS Module endorses the 21st century skills framework provided by Osman & Neelavany (2010). The researcher has chosen this framework as it takes into account the spiritual and noble values as an added value to the 21st century skills framework proposed by NCREL and Metiri Group (2003). This is to ensure that it is aligned with the National Educational Philosophy in Malaysia which conforms to the Physical, Emotional, Spiritual, and Intellectual concepts. The 21st century skills framework provided by NCREL and Metiri Group (2003) is composed of four main domains, which are digital era literacy, inventive thinking, effective communication, and high productivity. Table 2 shows five domains in the 21st century skills along with the descriptions. Meanwhile Table 3 demonstrates how each domain in the 21st century skills are applied in the STEM-21CS Module.

Table 2. 21st Century Skills

Digital age literacy	• Basic literacy, scientific literacy, economic literacy and technology literacy • Visual literacy and information literacy • Multicultural literacy and global awareness
Inventive thinking	• Adaptability, managing complexity, and self-direction • Curiosity, creativity and risk taking • Higher-order thinking and sound reasoning
Effective communication	• Teaming, collaboration and interpersonal skills • Personal, social and civic responsibility • Interactive communication
High productivity	• Prioritizing, planning, and managing for results • Effective use of real-world tools • Ability to produce relevant, high-quality products
Spiritual and noble values	• Thankful to God • Having an interest and curiosity toward the environment • Being honest and accurate in recording and validating data • Being diligent and persevering

Sources: NCREL & Metiri Group (2003); Osman & Neelavany (2010)

Table 3. Inculcation of 21st Century Skills through the STEM-21CS Module

Domain	**Example of activities for the topic of dynamic**
Digital age literacy	• Students find relevant information from reliable websites. • Students use advanced technological devices like digital cameras to record the evidence in project.
Inventive thinking	• Students play the role of engineers who need to design an efficient water wheel that can generate power. • Students need to use their knowledge in science and technology, and skills in mathematics to consider the features of a good water wheel.
Effective communication	• Presentation in the classroom. • Students use a variety of platforms to share the design of their water wheel such as YouTube, Facebook, email, blogs, etc.

High productivity	• Students make portfolios for the use of recyclable materials to design an efficient water wheel that is useable in the real-life context.
Spiritual and noble values	• Students carry out teamwork and instil values of collaboration among team members. • Students exhibit a sense of responsibility for their own investigation by collecting data honestly.

Conclusion

In conclusion, the challenging life in the 21st century demands that Malaysians be knowledgeable and skilled in the field of STEM. Strengthening STEM education can help students acquire knowledge and skills needed for them to compete in work-life in the future. Besides, STEM education, which emphasizes an interdisciplinary approach is essential to cope with global and local challenges. The engineering practices applied and integrated with science and mathematics is needed in designing a technology that is capable of solving problems in the real-world. With the connection of all four disciplines, expectantly students can be equipped with the 21st century skills which are absolutely necessary in this new era.

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