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An Interdisciplinary Approach for Biology, Technology, Engineering and Mathematics (BTEM) to Enhance 21st Century Skills in Malaysia

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ABSTRACT

An interdisciplinary approach for Biology, Technology, Engineering and Mathematics (BTEM) is suggested to develop 21st century skills in the Malaysian context. BTEM allows students to master biological knowledge and at the same time to be adroit in other sub discipline skills. Students master factual knowledge of biology and skills of the 21st century simultaneously. The two main teaching and learning strategies applied in BTEM are problem-based learning and inquiry-based learning. Students are exposed to real world problems that require them to undergo inquiry processes to discover the inventive solutions. The content knowledge of biology adheres to the Malaysian Integrated Curriculum for Secondary Schools. The essence of engineering is inventive problem solving. Incorporation of information communication technologies in teaching and learning will be able to fulfil the needs of the current Net Generation. Mathematics plays an important role as computational tools, especially in analysing data. The highlighted 21st century skills in BTEM include digital literacy, inventive thinking, effective communication, high productivity, and spiritual and noble values.

Keywords: BTEM (Biology, Technology, Engineering, Mathematics), inquiry-based learning, problem-based learning, 21st century skills

INTRODUCTION

The world of knowledge expands every day at a rate that is almost incomprehensible (Fogarty & Pete, 2010). The endless flow of information is exacerbated by the extraordinarily fast expanding rate of information and communication technology (ICT) in this century. In the 21st century, any rigorous education system must refer to the mastery of content and skills simultaneously. 21st century students need in-depth understanding of factual knowledge and skills that they receive in the disciplines to transform it into a circumstance changing context. In addition, students need to be able to design, evaluate and manage their own work (Darling-Hammond, 2010). Students need to learn how to think, learn, solve problems, communicate, collaborate and contribute to the society (Kay, 2010). This is because high academic achievement no longer guarantees a good career.

Like other competitive countries in the world, Malaysia realises the necessity of 21st century skills in strengthening the nation's ability to compete in the global arena. In 2010, Malaysia joined the Programme for International Student Assessment (PISA) and results show that Malaysian students fell below the international mean of 500 in science (Walker, 2011). The PISA results show that Malaysian students have not adapted to the changing world. PISA results are significant because these assessments measure the 21st century skills, including critical thinking and problem solving skills. The failure is because of the lack of emphasis on higher order thinking skills in the country's education system (Ministry of Education Malaysia, 2012). Research finds that most of the biology teachers are still practicing outdated teaching and learning (T&L) methods in the biology classroom. Teachers convey biology facts directly to the students and encourage rote memorization of the factual knowledge for examination purposes (Chiel, McManus, & Shaw, 2010) whereas biology teachers should in fact relate these biology concepts to real life contexts to enhance meaningful learning among the students and avoid giving them a negative perception that learning biology is a burden (Hall, Reiss, Rowell, & Scott, 2003).

Malaysia is becoming a hub for biotechnology and it is believed that this will be able to provide 70,000 work opportunities and increase the national income up to RM30 billion (8 billion USD) in 2020 (Ismail, 2011). Nevertheless, Malaysia is facing a deficiency in high-skilled local workforces in the fields of Science, Technology, Engineering and Mathematics (STEM). The policy of attaining 60% science and 40% art enrolment in education is reported to be a failure (Mohamad Yusof, 2008). In 2007, only 29% of secondary and tertiary students were enrolled in the science stream (Bernama, 2012). In 2012, this figure declined to less than 20% enrolment in the upper level secondary science stream (Ng, 2012). These figures are really alarming and the Malaysia Ministry of Education needs to take drastic actions to raise the enrolment of students into the science stream. Otherwise, it may stunt the efforts of the Malaysian government to improve attainment in STEM fields in order to turn Malaysia into a high-income country.

RATIONALE OF BTEM IMPLEMENTION IN MALAYSIA

The biology curriculum in Malaysia is content-and-outcome based and this curriculum model tends to encourage teachers to use fragmented T&L methods (Nordin et al., 2008), which limit the delivery of abstract and complex biological concepts (Othman, 2008). BTEM Module is trying to initiate the changes from fragmented T&L to an interdisciplinary approach. Furthermore, Malaysia's implementation of the integrated biology curriculum reflects a horizontal integration across different subjects (Ministry of Education Malaysia, 2005). An interdisciplinary curriculum can be defined as an approach that consciously applies methodology and language from more than one discipline to examine a central theme, issue, problem, topic, or experience (Jacobs, 1989). One of the typical strategies used in the interdisciplinary approach is problem-centric, where knowledge from several disciplines are connected to examine complicated real-life problems (Nikitina, 2006). Biology in the 21st century has become more dependent on other disciplines such as engineering, computer science, physics, chemistry and mathematics to solve higher levels of complex problems, especially those related to health, food, energy and the environment (National Research Council, 2008; Robinson *et al.*, 2010; Wake, 2003, 2008). Solving complex problems will require that students go far beyond only their biology content knowledge. They are required to understand what connections exist across disciplines, especially in engineering and technology and how to make those connections. Preparing future biologists without offering them the exposure and experience with engineering and technology will result in their failure to survive in the competitive environment (Labov, Reid & Yamamoto, 2010; National Research Council, 2003).

The core knowledge in BTEM is focused on the discipline of biology. The content knowledge of biology adheres to the Malaysian Integrated Curriculum for Secondary Schools. Inventive problem solving skills from engineering disciplines will be inculcated in the problem based learning (PBL) processes. Transmission of biology knowledge is aided by applying ICT in the T&L process. Students are allowed to surf the internet for relevant information, use e-tools (email, Facebook, Twitter etc.) for communication purposes and application tools provided by Microsoft Office (MS Word, MS Power Point, MS Excel etc.). Technology has been immersed as part of the students' life with the integration of ICT in science T&L (Osman, Abdul Hamid & Hassan, 2009). Rapid advances in ICT have changed the learning styles of many students of the Net Generation. These students have grown up in a world where technology is second nature to them (Annetta, Cheng, & Holmes, 2010). Online social networking and electronic-based resources are increasingly being used to enhance student understanding and interest in biology (Musante, 2008). ICT also encourages learning in a constructive context (Mikropoulos, Katsidis, Nikolou, & Tsakalis, 2003). Effective and relevant T&L strategies are necessary to fulfil the needs of today's Net Generation, who prefers digital resources to access information, communicate, and solve problems (Oblinger & Oblinger, 2005).

Developing the connection between biology and mathematics is one of the most important ways to shift the paradigms of both established science disciplines. The process of connecting between the disciplines of biology and mathematics should start as early as possible in the educational process as a preparation to combine both disciplines at tertiary levels of study (Šorgo, 2010). Incorporation of mathematics into biology curricula is critical for developing quantitative process skills, which are demanded in modern biology (Depelteau, Joplin, Govett, Miller, & Seier, 2010; Duncan, Bishop, & Lenhart, 2010; Marsteller *et al.*, 2010; Tra & Evans, 2010). Recent achievements in integration of modern biology and technology have dramatically created new opportunities for the application of mathematics to biology (National Research Council, 2005). This new generation of biologists will routinely use mathematical models and computational approaches to draw hypotheses, design experiments, and analyse results (Robeva & Laubenbacher, 2009).

HOW CAN BTEM BE IMPLEMENTED IN THE MALAYSIAN CONTEXT?

Since traditional didactic T&L methods have been firmly rooted in the Malaysian classroom, it will be a big challenge to shift traditional T&L methods into 21st century T&L methods. As a starting point, we may want to try to incorporate traditional subject-content with 21st century skills (Fogarty & Pete, 2010). Therefore, the researchers propose to develop a BTEM Module, which integrates T&L on the topic of nutrition (refer to the Integrated Curriculum for Secondary Schools Biology Form 4) with technology, engineering and mathematics skills.

The BTEM Module is written to adhere to the existing Integrated Curriculum for Secondary School Biology Form 4 in which biology, technology, engineering and mathematics will be taught together across the whole module. The students are exposed to real world jobs such as food engineer, dietician, and nutritionist as they go through the module. It is aimed at inculcating the students' interest toward relevant jobs in the future. Table 1 shows an example of an activity in the BTEM Module in which the students are given roles as food engineers who apply biology, technology and mathematics to solve the problem of food shortage by designing and creating a farming method for the future.

Implementation of BTEM may be constrained by the time allocation as suggested in the Form 4 Biology Yearly Plan in which 7-8 weeks is allocated for the topic of nutrition. Besides that, the researchers also need to take into consideration the readiness of parents, teachers, students and school administrators before implementing the proposed module. The most important aspect that needs to be considered is the availability of facilities as part of the school infrastructure, especially well maintained computer labs with internet connection, and biology labs. In order to avoid "culture shock", briefing and practice sessions will be conducted before the real implementation. Due to the Smart School Project (since 1997) and the Teaching & Learning of Mathematics and Science in English Programme (2003-2013), almost all secondary schools are well equipped with computer labs, science laboratories, internet, LCD projectors, note books, etc. The researchers also believe that Malaysian students are not "digitally blind". This is because they have been intentionally taught ICT literacy since Standard one. Moreover, today's Net Generation inevitably has close contact with digital devices in their daily life. Many young children are already very familiar with current technologies, like iPads or iPhones on which most of them play games. We need to realise that the Net Generation prefers digital resources to access information, communicate, and solve problems and hence, we need to adapt the current T&L strategies to match the students' needs (Oblinger & Oblinger, 2005). Thus, the BTEM Module encourages students to use current technologies such as digital cameras, video cameras, webcams, and smart phones in the T&L process. The BTEM Module also advocates Smart School pedagogies, which are characterised by more emphasis on student-centered learning where they are responsible for their own learning. The students will apply both problem-based learning (PBL) and inquiry-based learning (IBL) to solve real world problems. Performance based assessments such as rubrics and portfolios will be applied because they are more relevant to PBL and IBL T&L strategies.

Table 1. Example of an Activity in the BTEM Module

Activity	Future Farming
Time required	2-3 weeks
Learning outcomes	• Explain the need to improve the quality and quantity of food. • Explain the efforts to diversity food production. • Explain ways to improve the quality and quantity of food production in the country.
Activity description	In this activity, you are a food engineer. You need to use your knowledge in biology, food technology and skills in mathematics to solve problems regarding the lack of arable land for planting, and effects of climate that threaten food production.
What do food engineers do?	Food engineers apply agricultural engineering, mechanical engineering and chemical engineering principles to solve food production problems. They need to think carefully about how much money their projects will cost to build and maintain food and quality. In the 21st century, engineering solutions also need to take environmental concerns into account and the engineers also need to be careful about how they use natural resources. Their solution should meet the needs of the people at the present time as well as the needs of the future generations.

Creative exemplar (**Engage**) Video URL: http://www.youtube.com/watch?v=LHAEfAai8Ko	**We can plant on the rooftop!** **New York City's First Rooftop Hydroponic Farm to Yield 30 Tons of Produce Annually!** Using hydroponics and climate control technology, the farm is serving up hundreds of pounds of super local lettuce to New York City's markets on the same day it's harvested. Further information available at: http://www.fastcompany.com/1763555/gotham-greens-brooklynsnew-high-tech-rooftop-farm
Your task (**Explore**)  Photo: A seven-month-old child with a weight of 3.4kg Source: http://www.cbsnews.com/2100-202_162-20083500.html *Remark: Students are encouraged to collect relevant information from the internet and other sources.	**Scenario:** Africa is the only region where the number of hungry people grew over the period 1990-1992 and 2010-2012, from 175 million to 239 million, with nearly 20 million added in the past four years. The prevalence of hunger, although reduced over the entire period, has risen slightly over the past three years, from 22.6% to 22.9% - with nearly one in four hungry. And in sub-Saharan Africa, the modest progress achieved in recent years up to 2007 was reversed, with hunger rising 2% per year since then. (Source: http://www.fao.org/news/story/en/item/161819/icode/) Your team challenge is to design a sustainable farming method to increase the quality and quantity of food in Africa. You need to consider the use of recyclable materials and be cost-effective, which would allow the affected Africans to be able to afford to use it. The following step-by-step guidelines may be useful in helping your group to solve the problem. 1. Define the specific problem. 2. Analyse the problem (the causes of the problem, consequences of the problem). 3. State the ideal solution to the present situation. 4. Generate ideas to solve the problem (brainstorming). 5. Find a solution (illustrate the design, propose the budget, how does it work?). 6. Implement the solution (build the design into a real unit – just 1 unit, and try it out with real plants).

(Explain & Extend)	• Your group will prepare a portfolio for your idea. • Defend and share the idea through a group presentation (10 minutes). Show the real product during the presentation. • You should share your experiences through the blog created earlier. • A mini exhibition will be held in your school to share the creative idea with the school community. • You are encouraged to upload your group's design onto YouTube and be prepared to receive comments from YouTube users.
Evaluate	• Performance based assessment. • A rubric form is used to evaluate the effectiveness of the design in the aspect of cost, user-friendliness, creativity, environmentally-friendly, usability, relevance etc. – Peer-assessment, self-assessment, teacherassessment.

WHY PROBLEM-BASED LEARNING AND INQUIRY-BASED LEARNING IN THE BTEM MODULE?

The idea of the BTEM Module originated from STEM education. The major elements of STEM education are the incorporation of PBL and IBL. These two approaches are able to help students to acquire basic 21st century skills. An inquiry approach is the nature of science, whereas inventive problem solving is the essence of engineering (Mastascusa, Snyder, & Hoyt, 2011). Inquiry is the driver of complex thinking during problem solving processes (Barell, 2010). While searching for information by questioning, IBL can be incorporated into many different formats to solve authentic problems (Borich, Hao, & Aw, 2006). The problems in the BTEM Module are complex, ill-structured, and unrealistic problematic scenarios that embody the major concepts to be mastered and understood. Students can become active learners and taught to ask good questions, conduct investigations, draw conclusions and find the best solution for the problem. The activity requires students to achieve the highest level in Bloom's Taxonomy, namely generating testable hypotheses or inventing new solutions for the problem (Barell, 2010; Mastascusa et al., 2011; Trilling & Fadel, 2009).

The inquiry level incorporated into the BTEM is guided inquiry. The activities in the BTEM Module are designed based on the 5E learning cycle: Engage, Explore, Explain, Extend and Evaluate. The KWHLAQ approach is applied to assist students in generating questions on the specific learning unit (Barell, 2010).

- **K:** What do we think we already ***know***?
- **W:** What do we ***want*** and need to find out?
- **H:** ***How*** will we proceed to investigate our questions? ***How*** will we organize time, access resources and conduct the reporting? ***How*** will we self-assess our progress?
- **L:** What are we ***learning*** (daily)? And what have we ***learned*** at the end of our investigations?
- **A**: How and where can we ***apply*** the results of our investigations into daily lives?
- **Q**: What new ***questions*** do we have now? How might we pursue them in our next units?

BTEM AND 21ST CENTURY SKILLS

STEM and 21st century skills are mutually supportive and naturally matched. STEM is a very effective way to acquire knowledge and 21st century skills (Partnership for 21st Century, 2011). STEM curriculum highlights 21st century skills in each discipline (Bybee, 2010). STEM allows students to work together to create innovative solutions to real-world problems and communicate their solutions with others (Beers, n.d.). BTEM is closely related to STEM. Therefore, BTEM is believed to be able to integrate 21st century skills into the existing biology curriculum effectively. The conceptual framework for 21st century skills in the Malaysian context is modified based on the conceptual framework from the North Central Regional Education Laboratory (NCREL) and the Meriti Group, incorporating digital era literacy, inventive thinking, effective communication, high productivity, and spiritual and nobles values (Osman, Tuan Soh, & Mohamad Arsad, 2010). Table 2 shows how each domain of 21st century skills is inculcated through the BTEM Module.

The ever-changing ICT has become a driver of change, a bridge to excellent academic achievement, and a platform for informed decision making and accountability (enGauge, 2003). Therefore, students need to be competent in multiple digital age literacy and this includes basic literacy, scientific literacy, economic literacy, technology literacy, visual literacy, information literacy, multicultural literacy and global awareness.

Research findings show that students who are involved in inventive activities are more comfortable in solving new and unfamiliar problems (Taylor, Smith, Stolk & Spiegelman, 2010). Inventive thinking comprises the following life skills: adaptability and managing complexity, self direction, curiosity, creativity, risk taking, higher-order thinking and sound reasoning (enGauge, 2003; Osman *et al*., 2009).

As ICT becomes more pervasive in society, citizens become highly reliant on ICT in effective communication. However, emerging ICT can also present ethical dilemmas. Thus, it is very important for citizens to have the ability to manage the impact on their social, personal, professional, and civic lives through effective communication skills. Effective communication skills consist of the following criteria: teaming and collaboration, interpersonal skills, personal responsibility, social and civic responsibility, and interactive communication (enGauge, 2003).

High productivity is a very important indicator that shows whether a person is successful or failing in the workforce. This skill should be infused in school curricula as an early preparation for students before they join or become part of the future workforce. The criteria for high productivity skills include prioritizing, planning, and managing for results, effective use of real-world tools, and ability to produce relevant, high-quality products (enGauge, 2003).

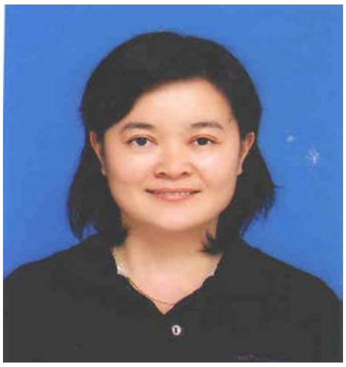
The ultimate aim of the National Education Philosophy is to produce holistic human capital consisting of individuals who are emotionally, intellectually, physically and spiritually (JERI) balanced and integrated. Thus, it is necessary to inculcate spiritual and noble values as part of 21st century skills for the Malaysian context (Osman *et al*., 2010). Biology learning experiences can be used as a means to develop spiritual and noble values in students (Ministry of Education Malaysia, 2005). Examples of spiritual and noble values are being thankful to God, having an interest and curiosity toward the environment, being honest and accurate in recording and validating data, being diligent and persevering, etc.

Table 2. Inculcation of 21st Century Skills through the BTEM Module

Domain	Example of activities for the topic of nutrition
Digital age literacy	• Students find relevant information from reliable websites. • Students use advanced technological devices like digital cameras to record the evidence in experiments.
Inventive thinking	• Students play the role of food engineers who need to design new methods to increase the quality and quantity of food. • Students design an experiment to investigate the effect of light intensity on the photosynthesis rate.
Effective communication	• Students use a variety of platforms to share the findings of their experiment such as via YouTube, email, Facebook, blogs etc. • Presentation in the classroom.
High productivity	• Students write proposals for the use of recyclable materials to design a new farming method that is useable in the real life context.
Spiritual and noble values	• Students carry out teamwork and instill values of collaboration among team members. • Students exhibit a sense of responsibility for their own investigation by collecting data honestly.

CONCLUSION

In the era of an endless flow of information, it is impossible to transmit every new bit of information or knowledge from the teachers to the students. An interdisciplinary approach is implemented with the idea that subject-specific learning is not relevant to young school leavers in the twenty-first century. They need to be taught lifelong learning skills to acquire information by themselves. Singapore is an exemplar nation that has started to set "teach less, learn more" as their education vision for the 21st century. By mastering 21st century skills, it is hoped that it will help Malaysia to achieve its National Education Philosophy which is to build human capital comprised individuals who are intellectually, emotionally, physically and spiritually balanced.



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