Research Journal of Applied Sciences, Engineering and Technology 6(16): 2976-2983, 2013
DOI:10.19026/rjaset.6.3681
ISSN: 2040-7459; e-ISSN: 2040-7467

Submitted: January 08, 2013 Accepted: January 31, 2013 Published: September 10, 2013

Research Article

A Conceptual Framework for the Integration of 21st Century Skills in Biology Education

Lee Chuo Hiong and Kamisah Osman
Faculty of Education, National University of Malaysia, 43600 UKM Bangi, Selangor, Malaysia

Abstract: The main objective of this study is to propose the conceptual framework for the integration of 21st century skills in biology education in Malaysia. An interdisciplinary approach for Biology, Technology, Engineering and Mathematics (BTEM) is suggested to imbibe 21st century skills into the existing Biology curriculum. Solving complex and interdisciplinary worldwide biology problems will require students to understand what connections exist across disciplines and how to make those connections. BTEM allows students to master biological knowledge and at the same time to be adroit in other sub disciplinary skills. The main teaching and learning strategies that apply in the BTEM subjects are problem-based learning and inquiry-based learning which require the coordination of both knowledge and skills simultaneously. This is intended to enhance the students' abilities to construct their own knowledge through the relevant hands-on and minds-on activities. The essence of engineering is production of design for the inventive problem solving. Integrating advanced information communication technologies such as e-tools and World Wide Web resources are believed to be able to fulfil the learning style needs of the current 'Net Generation'. Mathematics plays an important role providing computational tools for biology and engineering, especially in analysing data. The expected outcomes of BTEM implementation are the inculcation of 21st century skills digital literacy, inventive thinking, effective communication, high productivity, spiritual and noble values in Malaysian students.

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

INTRODUCTION

The National Biotechnology Policy is one of the Malaysia's Government Transform Projects to accelerate the attainment of Vision 2020. The National Biomass Strategies is launched in 2011 to boost Malaysia's ability to be the hub for biotechnology. This policy is believed to be able to provide 70,000 work opportunities and increases the national income up to RM 30 billion in 2020 (Ismail, 2011). Nevertheless, Malaysia is facing a deficit in high-skilled local workers for Science, Technology, Engineering and Mathematics (STEM). Policy 60 (science): 40 (art) students is reported to be a failure (Mohamad Yusof, 2008). Data shows that students' inclination towards the science subject is still relatively low. Since 2007 only 29% of secondary and tertiary students enrolled into science streams (Bernama, 2012). This may stunt the Malaysian government's efforts to improve attainment in STEM fields thus affecting the aim to become a high income country.

Biology education in Malaysia: The ultimate aim of the Malaysia biology curriculum for upper secondary level is to provide students with the knowledge and skills in science and technology to enable them to solve problems and make decisions in everyday life based on scientific attitudes and noble values. Students who have followed the biology curriculum will gain a strong foundation enabling them to pursue further education in biology at post-secondary level. The curriculum also aims to develop a concerned, dynamic and progressive society with a science and technology culture that values nature and works towards the preservation and conservation of the environment (Ministry of Education Malaysia, 2005). The students who take biology as their elective pure science subject would take up careers in the field of science and technology and play a leading role in this field for national development (Ministry of Education Malaysia, 2005).

The Biology curriculum in Malaysia is content-and-outcome based and encourages teachers to use fragmented T and L methods (Nordin and Othman, 2008). Fragmented T and L methods limit the delivery of abstract and complex biological concepts (Othman, 2008). Many researchers have shown that most of the biology teachers are still applying traditional and out-dated methods in teaching biology. Teachers convey biology facts directly to the students and encourage rote memorization of the factual knowledge for examination

Corresponding Author: Kamisah Osman, Faculty of Education, National University of Malaysia, 43600 UKM Bangi, Selangor, Malaysia

(Chiel *et al*., 2010). Instead of exam-orientated, students should be trained to solve the real world problems in Biology (Hall *et al*., 2003).

T&L methods influence the students' performance in biology (Mahamod and Mustapha, 2007). Results of Trends in International Mathematics and Science Study (TIMSS) year 2007 shows that Malaysia students failed to achieve minimum international standard of 500 points for Biology, gaining only 469 points (Thomson and Buckley, 2007). In 2010 Malaysia joined the Programme for International Student Assessment (PISA) and results shows that Malaysian students gained an average score of 422 points in science (Walker, 2011). This failure is due to a deficit of higher order thinking skills in the education system as a whole (Ministry of Education Malaysia, 2012). Evidences shows that the high performance countries in PISA - Australia, Finland, Hong Kong, Japan, Canada, Netherlands, New Zealand, South Korea and Switzerland -emphasize both content and 21st century skills in their school curriculum (Senechal, 2010). In order to build up the ability to compete at international level the Ministry of Education has started to infuse entrepreneurship, creativity, design and technology elements through the Primary School Standard Curriculum (*Kurikulum Standard Sekolah Rendah,* KSSR) in 2011. The existing Biology curriculum is focused on Thinking Skills and Thinking Strategies (TSTS) to stimulate thoughtful learning. TSTS are higher order thinking skills which involve various critical and creative thinking skills (Ministry of Education Malaysia, 2005). However the TSTS may not be enough to equip students with living skills to survive in a competitive world and the Biology curriculum in Malaysia should be revised so that relevant 21st century knowledge and skills are simultaneously developed in students (Siraj, 2008). The Biology curriculum should be integrated with other disciplines to optimise the acquisition of a rapidly expanding information base (Nordin and Othman, 2008).

CONCEPTUAL FRAMEWORK

Interdisciplinary approach of BTEM: Interdisciplinary can be defined as a knowledge view and curriculum 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 strategy uses in the interdisciplinary approach (Fig. 1) is problem-centric, connects knowledge from several disciplines to examine complicated real-life problems (Nikitina, 2006). Interdisciplinary approach is implemented with the idea that subject-specific learning is neither important nor relevant to young school leavers in the twenty-first century (Hardy *et al*., 2008).

The 21st century biology requires interdisciplinary approaches across different disciplines such as engineering, computer science, physics, chemistry and mathematics to deal with the higher level of complex problems, especially in regards to health, food, energy and the environment which are becoming more dependent on other disciplines to collaborate in providing new applications, new methods, new techniques and new tools (National Research Council, 2008; Robinson *et al*., 2010 ; Wake, 2003, 2008). In the 21st century "*the New Biologist is not a scientist who knows a little bit about all disciplines but a scientist with deep knowledge in one and a "working fluency in others."* (National Research Council, 2009). To succeed teaching through this new interdisciplinary perspective requires new approaches, materials and pedagogies (Jungck *et al*., 2010; National Research Council, 2003, 2008). Solving complex, interdisciplinary problems will require that students go far beyond their biology content knowledge only. They are required to understand what connections exist across disciplines and how to make those connections. Preparing future biologists without offering them the exposure and experience with engineering and technology skills will fail to produce students who are able to perform effectively in an increasingly competitive environment (Labov *et al*., 2010; National Research Council, 2003).

BTEM is highly relevant to the STEM curriculum. The major element of the STEM curriculum is the incorporation of Problem Based Learning (PBL) and Inquiry Based Learning (IBL). Constructivist theory becomes the backbone that supports both PBL and IBL. Likewise, BTEM is also based on constructivist theory (Sanders, 2009). The student needs to incorporate their current and prior understanding while discovering new knowledge and should be continuously assimilating and accommodating knowledge, reflecting on it and their experiences (Nuangchalerm, 2009). The inquiry process can provide students with opportunities to explore and understand the natural world by the mselves, they become independent critical and creative thinkers.

The core of BTEM is Biology but with the application of Information and Communication Technology (ICT) during T and L processes; these ICT skills include surfing the internet for relevant information, usage of e-tools for communication purposes and application tools provided by the Microsoft office (Ms Words, Ms Power point, Ms Excel etc.).Technology has been immersed as part of the students' life with the integration of ICT in science T and L (Osman *et al*., 2009). Rapid advances in information technologies have changed the learning styles of many students of the Net Generation. These students have grown up in a world where technology is

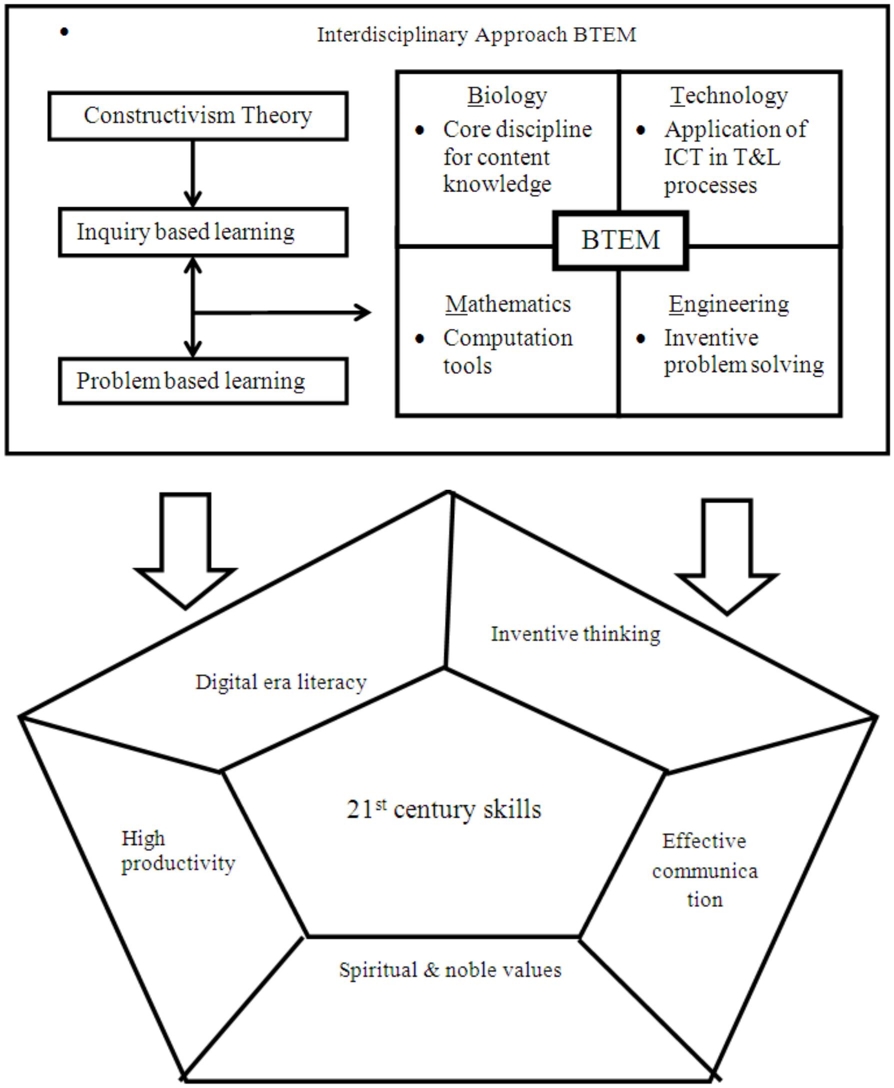

Fig. 1: Conceptual framework of interdisciplinary approach BTEM

second nature to them (Annetta *et al*., 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 *et al*., 2003). Effective and relevant teaching and learning (T and L) strategies are necessary to fulfil the needs of today's Net Generation because they prefer digital resources to access information, communicate and solve problems (Oblinger and Oblinger, 2005).

The fragmented or separated teaching of Biology and Mathematics has prevented the integration of both disciplines (Bialek and Botstein, 2004). Developing the connections between Biology and Mathematics is one of the most important ways to shift the paradigms of both established science disciplines. The process of connecting these two disciplines should start as early as possible in the educational process as a preparation to combine both disciplines at graduate and postgraduate levels of study (Sˇorgo, 2010). Incorporation of Mathematics into the Biology curricula is critical for developing quantitative process skills demanded in modern biology (Depelteau *et al*., 2010; Duncan *et al*., 2010; Marsteller *et al*., 2010; Tra and Evans, 2010). Recent achievements in the integration of modern Biology with technology have created dramatic new opportunities for the application of mathematical processes to facilitate a better understanding of 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 and Laubenbacher, 2009).

Problem Based Learning (PBL): Teaching students to become inventive problem solvers have long been goals of science education. However, methods to promote

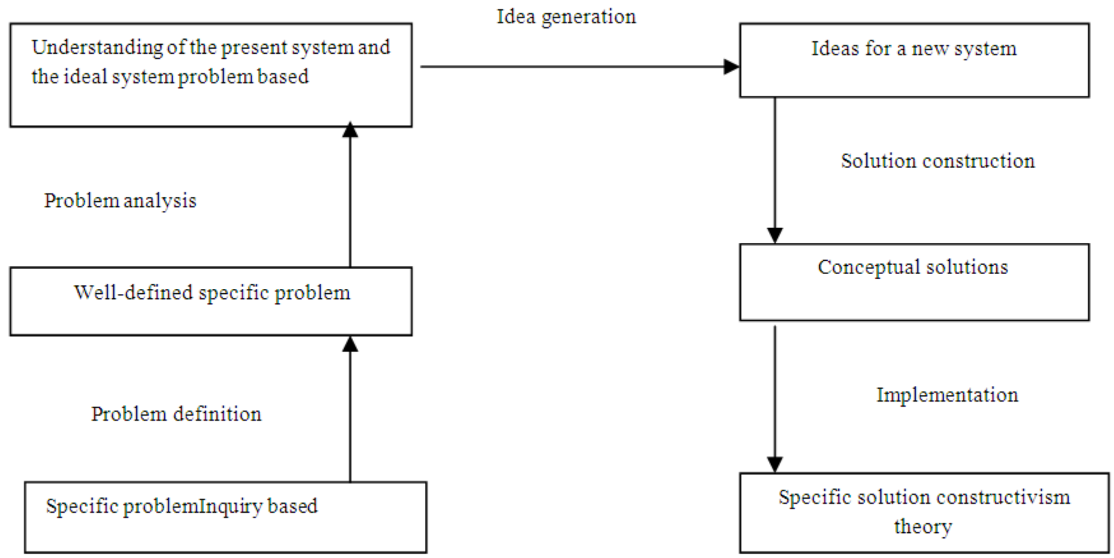

Fig. 2: Six-box schemes Unified Structured Inventive Thinking (USIT) (Toru, 2008)

creative thinking in scientific problem solving have not become widely known or used in the Science education (DeHaan, 2009). The essence of engineering is inventive problem solving (Mastascusa *et al*., 2011) and the recent Theory of Inventive Problem Solving (TRIZ), which was already well established in the field of engineering, promotes expansion to non-technical fields such as education (Marsh *et al*., 2004). For BTEM it is proposed to modify Six-Box Schemes Unified Structured Inventive Thinking (USIT) (Fig. 2) as the inventive problem solving procedures to solve authentic problems. BTEM exposes the students to engineering inventive problem solving skills. Inventive problem solving becomes the major element incorporated within inquiry based learning activities.

Inquiry Based Learning (IBL): Inquiry is the driver of the complex thinking during the problem solving processes (Barell, 2010) and IBL depends on the students' prior knowledge to construct new knowledge by themselves (Barrow, 2006). Thus, the student is supposed to function as an autonomous learner and the teacher as a facilitator. The teacher scaffolds the students by frequently reminding them to reflect, collaborate, ask themselves questions and justify their conclusions. Inquiry processes occur through the development of cognitive, meta-cognitive, psychomotor and social skills. When the students carry out experiments they apply different inquiry skills such as asking question, raising a hypothesis, planning an experiment to test the hypothesis, accessing and analysing data, making inferences, drawing conclusions, reporting and writing a research report. Students also apply meta-cognitive skills by engaging in reflective thinking throughout the learning stages. Students acquire psychomotor skills through manipulation of laboratory apparatus and using the computer. Inquiry processes also promotes collaborative social skills (Zion *et al*., 2004).

The main assumption is that inquiry skills develop best in the context of well-designed activities that are engaging to the student. BTEM places great emphasizes on self-directed hands-on and minds-on activities to help students construct an understanding of knowledge by themselves. We do not need to teach students particular science content or concepts (Kuhn and Pease, 2008). There are five essential features of inquiry as follows (National Research Council, 2000):

- Learners are engaged by scientifically oriented questions
- Learners give priority to evidence which allows them to develop and evaluate explanations that address scientifically oriented questions
- Learners formulate explanations from evidence to address scientifically oriented questions
- Learners evaluate their explanations in light of alternative explanations, particularly those reflecting scientific understanding
- Learners communicate and justify their proposed explanations.

21ST CENTURY SKILLS

There are five major current conceptual frameworks for 21st century skills-the Partnership for 21st Century Skills, the North Central Regional Education Laboratory (NCREL) and the Meriti Group, the Organisation for Economic Co-operation and Development, the National Leadership Council for Liberal Education and America's Promise (Dede, 2010). The conceptual framework for 21st century skills in the Malaysia context is modified based on the conceptual framework from the North Central Regional Education Laboratory (NCREL) and the Meriti Group. Spiritual and nobles values is the added value for the 21st century skills framework proposed by the NCREL and Meriti Group; digital era literacy, inventive thinking, effective communication and high productivity.

Digital era literacy: In order to succeed the 21st century skills program must see students increasing their information proficiency in multiple contexts. Digital age literacy includes the following (enGauge, 2003):

- **Basic literacy:** Basic literacy includes language and quantitative proficiencies to aid one's goals to be achieved with knowledge and potential at work and in society generally.
- **Scientific literacy:** Scientific literacy refers to understanding scientific knowledge, the concepts and processes needed for personal decision making, participation in civic, cultural affairs and economic productivity.
- **Economic literacy:** Economic literacy includes the ability to be alert to the development of economic problems, seeking alternative solutions, analysing costs and benefits, the incentives at work in economic situations, examining the consequences of changes in economic conditions and public policies, collecting and organizing economic.
- **Technological literacy:** Technological literacy refers to an understanding of the meaning of technology, its functions and operation as well as its efficiency and effectiveness to achieve specific goals.
- **Visual literacy:** Visual literacy refers to the ability to interpret, apply, appreciate and create images and video by using both conventional and 21st century media in ways that advance thinking, decision making, communication and learning.
- **Information literacy:** Information literacy refers to the ability to evaluate information across multiple resources critically, to recognize when information is needed, to locate, synthesize and use information effectively and accomplish these functions using technology, communication networks and electronic resources.
- **Multicultural literacy:** Multicultural literacy refers to the ability to understand and respect the similarities and differences in customs, values and beliefs of one's own culture as well as the culture of others.
- **Global awareness:** Global awareness includes the recognition and understanding of interrelationships among international organizations, nation-states, public and private economic entities, socio-cultural groups and individuals globally.

Inventive thinking: Research findings show that students who are involved in inventive activities are more comfortable solving new and unfamiliar problems (Taylor *et al*., 2010). Inventive thinking is made up of the following life skills (Osman *et al*., 2009):

- **Adaptability and managing complexity:** Adaptability and managing complexity refers to the ability to modify one's thinking, attitudes or behaviours to better suite the current or future environments as well as the ability to handle multiple goals, tasks and input while understanding and adhering to constraints of time, resources and systems.
- **Self-direction*:*** Self-direction s defined as the ability to set goals related to learning, plan for the achievement of those goals, independently manage time and effort and independently assess the quality of learning and any products that result from the learning experience.
- **Curiosity:** Curiosity is the catalyst behind one's desire to know - it is the spark of interest that leads to inquiry.
- **Creativity:** Creativity refers to the act of bringing something into existence that is genuinely new, original and of value either personally (of significance only to the individual or organization) or culturally (adds significantly to a domain of culture as recognized by experts.
- **Risk taking:** Risk taking includes a willingness to make mistakes, advocate unconventional or unpopular positions, to tackle extremely challenging problems without obvious solutions leading to personal growth, integrity and enhanced accomplishments.
- **Higher-order thinking and sound reasoning:** Higher-order thinking and sound reasoning includes the cognitive processes of analysis, comparison, inference and interpretation, evaluation and synthesis applied to a range of academic domains and problem-solving contexts.

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

- **Teaming and collaboration:** Teaming and collaboration refers to cooperative interaction among more than two individuals working together to solve problems and to achieve the same goals.

- **Interpersonal skills:** Interpersonal Skills include the ability to read and manage the emotions, motivations and behaviours of oneself and others in social interactive context.
- **Personal responsibility:** Personal responsibility refers to the depth of understanding about legal and ethical issues related to contemporary technology and an ability to apply the relevant knowledge to achieve balance, integrity and quality of life.
- **Social and civic responsibility:** Social and civic responsibility includes the ability to manage technology and use in a way that promotes public good.
- **Interactive communication:** Interactive communication refers to the ability to generate meaning through exchanges using a range of contemporary tools, transmissions and processes.

High productivity: High productivity is a very important indicator to show whether a person will succeed or fail in the workforce. This skill and ability should be infused into the school curriculum at an early age in order to prepare the students' as a future high-skilled workforce. The criteria for high productivity skills are as follows (enGauge, 2003):

- Prioritizing, planning and managing for results: Prioritizing, planning and managing for results refers to the ability to be organized efficiently to achieve the goals of a specific task.
- Effective use of real-world tools: Effective use of real-world tools includes the ability to use real-world tools (hardware, software, networking etc.,) to communicate, to collaborate, to solve problems and to accomplish 21st century tasks.
- Ability to produce relevant, high-quality products: Ability to produce relevant high-quality products refers to the ability to produce intellectual, informational products that serve real life purposes as a result of students using real-world tools to solve real-world problems.

Spiritual and noble values: The ultimate aim of the National Educational Philosophy is to produce holistic human capital in emotional, intellectual, physical and spiritual (JERI) terms. Thus, it is necessary to inculcate spiritual and noble values as a part of 21st century skills for the Malaysian context. Biology learning experiences can be used as a means to inculcate spiritual and noble values in students; these values encompass the following (Ministry of Education Malaysia, 2005):

- Having an interest and curiosity towards the environment
- Being honest and accurate in recording and validating data
- Being diligent and persevering
- Being responsible about the safety of oneself, others and the environment
- Realising that science is a means to understand nature
- Appreciating and practising clean and healthy living
- Appreciating the balance of nature
- Being respectful and well-mannered
- Appreciating the contribution of science and technology
- Being thankful to God
- Having critical and analytical thinking
- Being flexible and open-minded
- Being kind-hearted and caring
- Being objective
- Being systematic
- Being cooperative
- Being fair and just
- Daring to try
- Thinking rationally
- Being confident and independent.

CONCLUSION

The interdisciplinary approach of BTEM requires that 21st century skills are inserted into the existed biology curriculum. The 21st century skills conceptual framework for the Malaysian context is modified based on the framework suggested by NCREL and Meriti Group. It includes digital era literacy, inventive thinking, effective communication, high productivity, spiritual and nobles values. The incorporation of PBL and IBL into the learning experience is the essence of BTEM and its objective to cultivate students' ability to be engaged in scientific inquiry and discover biological contents by themselves. BTEM stresses that engaging in scientific inquiry requires coordination both of knowledge and skill simultaneously. Arguments between the emphasis that should be placed on scientific content and the emphasis placed on scientific practices will be reduced. According to North Central Regional Educational Laboratory and the Metiri Group achievement will be enhanced when the students have acquired 21st century skills successfully (enGauge, 2003).

REFERENCES

Annetta, L.A., M.T. Cheng and S. Holmes, 2010. Assessing twenty first century skills through a teacher created video game for high school biology students. Res. Sci. Technol. Educ., 28(2): 101-111.

Barell, J., 2010. Problem-Based Learning: The Foundation for 21st Century Skills. In: 21st Century Skills: Rethinking How Students Learn. Bellanca, J. and R. Brandt (Eds.), Solution Tree Press, Bloomington, pp: 175-199.

Barrow, L.H.,2006.Abriefhistoryofinquiry: From dewey tostandards.J.Sci.Teach. Educ., 2006(17): 265-278.

Bernama, 2012. Declining Interest in Science Education Alarming-Khaled. The Borneo Post, pp: 17-27.

Bialek, W. and D. Botstein, 2004. Introductory science and mathematics education for 21st century biologists. Science, 303: 788-790.

Chiel, H.J., J.M. McManus and K.M. Shaw, 2010. From biology to mathematical models and back: Teaching modeling to biology students and biology to math and engineering students. CBE Life Sci. Educ., 9: 248-265.

Dede,C.,2010.Comparing Frameworks for 21st Century Skills. In: Bellanca, J. and R. Brandt (Eds.), 21st Century Skills: Rethinking How Students Learn. Solution Tree Press, Bloomington, pp: 51-75.

DeHaan, R.L., 2009. Teaching creativity and inventive problem solving in science. CBE Life Sci. Educ., 8: 172-181.

Depelteau, A.M., K.H. Joplin, A. Govett, H.A. Miller and E. Seier, 2010. SYMBIOSIS: Development, implementation and assessment of a model curriculum across biology and mathematics at the introductory level.CBE Life Sci. Educ., 9: 342-347.

Duncan, S.I., P. Bishop and S. Lenhart, 2010. Preparing the "new" Biologist of the future: student research at the interface of mathematics and biology. CBE Life Sci. Educ., 9: 311-315.

enGauge, 2003. enGauge 21st Century Skills for 21st Century Learners: Literacy in the Digital Age. Retrieved from: www.ncrel.org/engauge

Hall, A., M.J. Reiss, C. Rowell and A. Scott, 2003. Designing and implementing a new advanced level biology course. J. Biol. Educ., 37(4): 162-167.

Hardy, G., A. Howes, D. Spendlove and G. Wake, 2008. Opportunities to confront and cross subject boundaries: Trainee teachers' perceptions of the differences and interrelationships between STEM subjects. Paper presented at the British Educational Research Association Annual Conference Heriot-Watt University, Edinburgh,.

Ismail, M.K., 2011. Biomas Kebangsaan Dilancar. Utusan, Malaysia, pp: 3.

Jacobs, H.H., 1989. Design Options for an Integrated Curriculum. In: Jacobs, H.H. (Ed.), Interdisiplinary Curriculum: Design and Implementation. Association for Supervision and Curriculum Development, pp: 13-24.

Jungck, J.R., H.D. Gaff, A.P. Fagen and J.B. Labov, 2010. "Beyond BIO2010: Celebration and opportunities" at the intersection of mathematics and biology. CBE Life Sci. Educ., 9: 143-147.

Kuhn, D. and M. Pease, 2008. What Needs to Develop in the Development of Inquiry Skills? Retrieved from: http://www.imap.educationforthinking.org/.

Labov, J.B., A.H. Reid and K.R. Yamamoto, 2010. Integrated biology and undergraduate science education: A new biology education for the twenty-first century? CBE Life Sci. Educ., 9: 10-16.

Mahamod, Z. and N.S.N. Mustapha, 2007. Strategi pembelajaran biologi di kalangan pelajar sekolah menengah. J. Pendidikan., 32(2007): 153-175.

Marsh, D.G., F.H. Waters and T.D. Marsh, 2004. 40 Inventive Principles with Applications in Education. Retrieved from: http://citeseerx.ist.psu.edu/viewdoc/summary.

Marsteller, P., L.D. Pillis, A. Findley, K. Joplin, J. Pelesko, K. Nelson, K. Thompson, D. Usher and J. Watkins, 2010. Toward integration: From quantitative biology to mathbio-biomath? CBE Life Sci. Educ., 9: 165-171.

Mastascusa, E.J., W.J. Snyder and B.S. Hoyt, 2011. Effective Instruction for STEM Disciplines: From Learning Theory. John Wiley and Sons, Inc., UK.

Mikropoulos, T.A., A. Katsikis, E. Nikolou and P. Tsakalis, 2003. Virtual environments in biology teaching. J. Biol. Educ., 37(4): 176-181.

Ministry of Education Malaysia, 2005. Integrated Curriculum for Secondary Schools: Curriculum Specifications BIOLOGY Form 4. Ministry of Education Malaysia, Putrajaya.

Ministry of Education Malaysia, 2012. Laporan Awal - Ringkasan Eksekutif Pelan Pembangunan Pendidikan Malaysia 2013-2025. Ministry of Education Malaysia, Putrajaya.

Mohamad Yusof, K., 2008. Basic education curriculum revisited: A look at the current content and reform in Malaysia. Paper Presented at the SEAMEO-RETRAC 11th Governing Board Meeting and Conference, Institute Aminuddin Baki Malaysia.

Musante, S., 2008. Critical conversations: The 2008 Biology Education Summit. BioScience, 58(8): 685-689.

National Research Council, 2000. Inquiry and the National Science Education Standards: A Guide for Teaching and Learning. Olson, S. and S. Loucks-Horsley (Eds.), Retrieved from: http://www.nap.edu/catalog/9596.html.

National Research Council, 2003. BIO2010: Transforming Undergraduate Education for Future Research Biologists. Retrieved from: http://www.nap.edu.

National Research Council, 2005. Mathematics and 21st Century Biology. Retrieved from: http://www.nap.edu.

National Research Council, 2008. The Role of Theory in Advancing 21st Century Biology: Catalyzing Transformative Research. Retrieved from: http://www.nap.edu.

National Research Council, 2009. A New Biology for 21st Century. Retrieved from: http://www.nap.edu.

Nikitina, S., 2006. Three strategies for interdisciplinary teaching: Contextualizing, conceptualizing and problem-centring. J. Curric. Stud., 38(3): 251-271.

Nordin, A.B. and I. Othman, 2008. Falsafah Pendidikan dan Kurikulum. In: Ke (Ed.) 2nd Edn., Quantum Books, Tanjong Malim.

Nuangchalerm, P., 2009. Cognitive development, analytical thinking and learning satisfaction of second grade students learned through inquiry-based learning. Asian Soc. Sci., 5(10): 82-87.

Oblinger, D.G. and J.L. Oblinger, 2005. Is It Age or IT: First Steps Toward Understanding the Net Generation. In: D.G. Oblinger and J.L. Oblinger (Eds.), Educating the Net Generation. Educause, pp: 21-220, Retrieved from: www.educause.edu/ educatingthenetgen/.

Osman, K., S.H. Abdul Hamid and A. Hassan, 2009. Standard setting: Inserting domain of the 21st century thinking skills into the existing science curriculum in Malaysia. Proc. Soc. Behav. Sci., 1(2009): 2573-2577.

Othman, T., 2008. Konsep Sains dan idea konstruktivisme. In: Aida Suraya, M.Y., M.A. Ahmad Fauzi and T. Othman (Eds.), Amalan Dalam Pengajaran and Pembelajaran: Sains, Matematik and Pembelajaran Berasaskan IC. Penerbit Universiti Putra Malaysia, Serdang.

Robeva, R. and R. Laubenbacher, 2009. Mathematical biology education: Beyond calculus. Science, 325: 542-543.

Robinson, G.E., J.A. Banks, D.K. Padilla, W.W. Burggren, C.S. Cohen, C.F. Delwiche, V. Funk, H.E. Hoekstra, E.D. Jarvis, L.Q. Johnson, M. Martindale, C.M.d. Rio, M. Medina, D.i.E. Salt, S. Sinha, C. Specht, K. Strange, J.E. Strassmann, B.J.S. lla and L. Tomanek, 2010. Empowering 21st century biology. BioScience, 60(11): 923-930.

Sˇorgo, A., 2010. Connecting biology and mathematics: First prepare the teacher. CBE Life Sci. Educ., 9: 196-200.

Sanders, M., 2009. STEM, STEM Education, STEMmania. Technol. Teacher, 68(4): 20-26.

Senechal, D., 2010. The Most Daring Education Reform of all American Educator. pp: 1-13. Retrieved from: http://www.aft.org/pdfs/ americane ducator/spring2010/Senechal.pdf.

Siraj, S., 2008. Kurikulum Masa Depan. Kuala Lumpur, Penerbit Universiti Malaya.

Taylor, J.L., K.M. Smith, A.P.V. Stolk and G.B. Spiegelman, 2010. Using invention to change how students tackle problems. CBE—Life Sciences Education, 9: 504–512.

Thomson, S. and S. Buckley, 2007. Informing Science Pedagogy: TIMSS 2007 Australia and The World. Retrieved from: www.acer.edu.au/timss.

Toru, N., 2008. Extension of USIT in Japan: A new paradigm for creative problem solving. Proceeding of the 4th TRIZ Symposium Japan. Laforet Biwako, Moriyama, Shiga, Japan.

Tra,Y.V.andI.M.Evans,2010.Enhancing Interdiscip linary mathematics and biology education: A microarray data analysis course bridging these disciplines. CBE Life Sci. Educ., 9: 217-226.

Wake, M.H., 2003. What is ''integrative biology''? Integr. Comp. Biol., 43(2003): 239-241.

Wake, M.H., 2008. Integrative biology: Science for the 21st century. BioScience, 58(4): 349-353.

Walker, M., 2011. PISA 2009 Plus Results: Performance of 15-year-olds in Reading, Mathematics and Science for 10 Additional Participants. Australian Council for Educational Research, Melbourne, Australia.

Zion, M., D. Shapira, M. Slezak, E. Link, N. Bashan, M. Brumer, T. Orian, R. Nussinovitch, B. Agrest and R. Mendelovici, 2004. Biomind: A new biology curriculum that enables authentic inquiry learning. J. Biol. Educ., 38(2): 59-67.