Systematic Review of Secondary School Biotechnology Teaching

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Abstract Various best practices of teaching biotechnology have been reported in many countries. However, the best practices of teaching biotechnology that could be appropriate for Malaysian education system was seldom reported. The aim of this study is to review the practices of teaching biotechnology in secondary school systematically. The procedures of systematic review are based on review methods developed by the EPPI-Centre for systematic reviews of educational research literature. The sampling time line for this study is all relevant studies from 1985 to 2018. The authors went through the abstracts of 2524 studies from scientific articles, journals, theses and scientific reports. As a result, 122 studies were successfully identified as potential samples. However, only 19 studies accepted in this systematic review after filtering the articles according to the inclusion and exclusion criteria. The criteria included instructional practice of teaching biotechnology in secondary school only, published between 1985 to 2018, languages that understood by the authors, involved ordinary secondary school students of pure science, agriculture & technology background and had not been included more than once in any publication. The authors found that using module, laboratory active-based learning, online learning platform and workshop were the common practice. However, the development of an appropriate module integrated with e-learning would enhance the learning of biotechnology among the secondary school students. The approaches used in the biotechnology teaching also cultivated the 21st century skills, such as problem-solving skills, inventive skills, technological literacy and effective communicative skills.

Keywords Teaching Biotechnology, Systematic Review, Inclusion and Exclusion Criteria, Best Practices

1. Introduction

Explosive development of biotechnology had an increasing impact on our society. The application of biotechnology in medicine, agriculture, industry and nutrition would be significant in the future. As the biotechnology industry grows, the government and the related agencies need to collaborate with the industries to provide the sufficient related workforces for the job market (Nugent & Lindburg, 2015). The proper information about biotechnology and its application in various area should be informed to the society (Josefsson, 1987). The responsibilities of educators especially in secondary schools is important to impact the basic knowledge to the secondary school students. Various studies have been introduced to teach biotechnology in schools.

2. Problem Statement

Systematic review of the practices of teaching biotechnology in secondary school is very much lacking in the literature compare to science subjects such as elementary science, secondary science and biology. The authors managed to find one literature of meta-analysis on the research trends and issues regarding biotechnology inclusion in technology education by Wells & Kwon (2009) in the open platform of literature search excluding grey literature, fugitive literature and closed platform that could not be accessed by the authors.

Wells & Kwon (2009) wanted to investigate current research trends in biotechnology education and to better understand the issues regarding to its implementation in the technology education classroom. They reviewed the findings from 28 prior studies to document research trends and issues related to the inclusion of biotechnology in technology education. It also provided insight into the current lack of classroom implementation.

Using evidence from reliable research to inform various instructional activities in teaching biotechnology in secondary school has the potential to ensure the best practice of teaching biotechnology. However, incorporating research into practice is time-consuming and make it impossible for most social scientists to keep abreast of primary research except within a few topic areas of special interest to them, so we need methods to help researchers easy access to evidence. Systematic reviews form a potential method for overcoming the barriers faced by clinicians when trying to access and interpret evidence to inform their practice (Cooper, 1986; Green, 2005).

Systematic reviews are of particular value in bringing together a number of separately conducted studies, sometimes with conflicting findings, and synthesizing their results (Green, 2005). Systematic reviews may include a statistical synthesis called meta-analysis but not necessarily used as part of this process, depending on whether the studies are similar enough so that combining their results is meaningful (Chalmers, Hedges & Cooper, 2002; Clarke, 2015).

The questions underlying the discussion of this study are as follows:

1. What are the best approaches of teaching biotechnology in secondary school?

2. What are the model been used in the approaches of biotechnology teaching in secondary school?
3. What are the 21st century skills cultivated in the approaches of biotechnology teaching in secondary school?

3. Literature Review

As biotechnology is important for the progress of future economy, education systems around the world have introduced biotechnology in their secondary school curriculum framework (Australia Education Council, 1994; Conner, 2000; Solomon, 2001). Biotechnology education is not a single subject in school but integrated into the curriculum of science, agriculture, biology and technology education in Australia, New Zealand, South Korea, USA and Malaysia (Moreland, Jones & Cowie, 2006; Nurnadiah, Evi & Kamisah, 2014; Rashidah, Norlidah & Dorothy, 2014; Wells & Kwon, 2009). In some countries, biotechnology have been proposed to be taught in primary school (Karadon & Sahin, 2010; Rota & Izquierdo, 2003). Lui and Chan (1999) also emphasized that the biotechnology education should begin as earlier as in secondary school, not from college onwards in Hong Kong. The understanding of Hong Kong secondary school students in biotechnology is still very far behind compared to USA, United Kingdom and Japan although the Hong Kong Industrial Support Fund had allocated HK$222 million for the development of biotechnology project in Hong Kong. Chaudhari (2013) also proposed that the instructional practices in biology should begin in primary school till secondary school where biology is part of the science textbook. From the exposure of biology since the primary school, it will help the students to learn biotechnology much easier in secondary school later. Biotechnology as one of the new branches in biology education involved some difficult terminology, study of complex organism in depth, molecular biology and genetics.

In this study, the practices of teaching biotechnology in various secondary schools, high schools, colleges and universities have been highlighted However, most of the studies found are of particular ways of teaching biotechnology in school. For example, Dunham, Wells & White (2002) introduced introductory activities and a problem-solving methodology in biotechnology education. Students must generate solution for the activities. From these activities, the constructivist learning environments would be promoted. In the other end, Negrin et al. (2007) introduced popular teaching in biotechnology such as using the television-based infrastructure with the presence of teacher. Furthermore, everyday images that related to biotechnology in students daily environment were used to substitute abstract elements in the diagrams.

4. Methods

Systematic review is a summary of the research literature that uses explicit, replicate methods to identify relevant studies, and then uses objective techniques to analyse those results (Card, 2012; Valentine, 2015).The goal of a systematic review is to limit bias in the identification, evaluation and synthesis of the body of the relevant studies that address a specific research question (Harden, 2010; Valentine, 2015).Therefore, systematic reviews aim to provide an objective of the best evidence (Petticrew & Roberts, 2006).Systematic reviews have been in use in one form or other in the social sciences for many decades, and are increasingly being used to support practice and policy.It also directs new research efforts(Egger, Smith & Altma, 2001; Petticrew & Roberts, 2006).

In this study, the authors used the Core Key-wording Strategy by EPPI-Centre (2001). Review methods developed by the Evidence for Policy and Practice Information and Co-ordinating Centre (EPPI-Centre) for systematic reviews of educational research literature is carried out in four phrases:

i. Searching and screening
ii.Keywording and generating the systematic map
iii.In-depth review and data extraction
iv.Synthesis

(Bennett, Lubben, Hogarth & Campbell, 2004; EPPI-Centre, 2001)

The selection of studies used in this systematic review was began by searching several databases and hand-searching in the library. The databases searched including *EBSCOhost, Springer Link, Science Direct, ERIC, The Canadian Center of Science and Education, Dissertation Abstracts International, Australia Digital Theses, Google Scholar*. A variety of keywords was used to locate the relevant studies such as “best practice”, “biotechnology teaching”, “biology teaching”, “science teaching”, “biotechnology instruction”, “biology instruction”, “science instruction”, “secondary school” and “systematic review”. Systematic study was conducted on six journals, namely *Education in Science, Journal of Research in Science, Journal of Biological Education, Science Education, School Science Review* and *Science Teacher*.

The sampling frame for this study is all relevant studies from 1985 to 2018.According to Bennett, Lubben & Hogarth (2003), the years from 1983 to 2003 or so has seen a number of changes in science teaching, of which one of the most significant has been the development of a wide range of materials to develop and understand scientific ideas. The last 15 years till 1980 parallels the implementation period for modern science curriculum projects (Sweitzer, Howe, Helgeson & Blosser, 1982). However, some interventions may have in use or in development for long before the first trial was published in an academic journal, so it is best to allow a wide margin of error around the start date (Petticrew and Roberts, 2006).

The process of systematic review was conducted from 22 October 2015 till 8 November 2018. According to Allen & Olkin (1999), the average amount of time needed for a systematic review was 46.25 days, however this figure ranged widely from 9 days to 105 days depends on the amount of reviews conducted. The authors went through the abstracts of 2524 studies from scientific articles, journals, theses and scientific reports. As a result, 122 studies were successfully identified as potential samples. However, only 19 studies qualified for use in this systematic review after filtering the articles according to the following inclusion and exclusion criteria:

1. It should focus on the instructional practice of teaching biotechnology in secondary school or high school whether it is taught as a single subject or as part of the science, agricultural and technology education curriculum.
2. It should be published between 1985 to 2018.
3. It should be published in the English and Malay languages which were understood by the authors.
4. It should involve normal secondary school or high school students only. The blind and other handicapped students are not the subjects of the study. The college school students and the unknown students background are not included in the study although they may be in the same range of ages.
5. It may involve secondary school students that is not from science stream such as agricultural and technology background.
6. It had not been included more than once. For example, the same study reported in a conference paper and a journal article.

Each study was carefully read and information collected based on the inclusion and exclusion criteria. Full reports were obtained and descriptive mapping was conducted. The inclusion and exclusion criteria was re-applied when in-depth review was conducted.

5. Findings

After thorough screening and in-depth reviewing, a total of 19 studies were selected as samples in this systematic review. All studies are in the form of refereed journal article except one dissertation and two conferences. The 19 articles were accepted following the selection criteria above. This has caused a very limited number of studies to be used. Three of the studies were presented with limited statistical data. The other sixteen studies provided various incomplete and inappropriate statistical data. Therefore, meta-analysis was not conducted in this study.

The results in Table 1 showed that the study is contributed mostly from the USA and Israel. The interest to conduct research in biotechnology instructional began actively from the year of 2000 and onwards. Most of the publication type are referred journal article that the authors searched through the databases and hand-searching.

Table 1. Frequencies of variable characteristics for included studies

Independent variable	Number of studies	Percentage (%)
Countries		
USA	7	36.85
Pakistan	1	5.26
Norway	1	5.26
New Zealand	1	5.26
Netherlands	1	5.26
Malaysia	1	5.26
Israel	3	15.79
Denmark	1	5.26
Brazil	1	5.26
Indonesia	2	10.54
Publication year		
1985-1989	0	0
1990-1994	0	0
1995-1999	1	5.26
2000-2004	2	10.54
2005-2009	4	21.04
2010-2015	6	31.58
2016-2018	6	31.58
Publication type		
Referred journal article	16	84.20
Dissertation	1	5.26
Conference paper	2	10.54

The results in Table 2 showed that the various instructional approach that could be used in teaching biotechnology in secondary school. The use of module and e-learning platform are the preferred approaches as the instructional practice in this study. Another approach that becoming popular in school nowadays is game-based activities. This study also found that learning workshop is still a preferred option for learning about ecology, environmental biotechnology and technical skills in biotechnology. Besides, the authors found that the learning of biotechnology could be integrated in other subjects such as English languages and Arts. The use of modelling instruction, which is adapted from the physics instruction, could be another possible option for biotechnology teaching in the future. The other traditional instructional practices used are cooperative learning, problem-based learning, project-based learning and active learning based laboratory work.

Table 2. The instructional practices in biotechnology teaching in secondary school

Approach	**Format group**	**Target model**	**Integrative**	**Learning outcome**	**Studies**
Module about environmental biotechnology	Case study	Grade 10-12 students ; non-science major	STS	HOTS, scientific & technological literacy	Dori, Tal, & Tsoushu (2003)
Writing assignment about issues in biotechnology	Indoor	Grade 7 and 10 students	STS; English	Effective communication skills;reasoning skill;basic literacy	Hohenshell, Hand & Staker (2004)
Drawing	Indoor	Second year secondary students	Art	Multicultural literacy; effective communication skills	Lannes, Flavoni & Demeis (1998)
Active learning based laboratory	laboratory kit	Secondary school students	ICT	Science process skills;attitude towards science/ biotechnology; technological literacy;problem-solving skill; inquiry-based learning	Taraban, Box, Myers, Pollard & Bowen (2007)
Online learning platform, “Viten.no”	VLE	Secondary school students aged 17 and 18	STS	Problem-solving skills	Lyngved (2009)
Modeling instruction	Scientific investigation	Secondary school students	STEM research process	Problem -solving skills; HOTS; inventive skills;reasoning skills; effective communication skills	Jackson, Dukerich & Hestenes (2008)
Gamified laboratory simulation, “Labster”	VLE	Secondary school students	ICT	Non-routine problem solving skills; technological literacy; attitude towards biotechnology	Bonde et al. (2014)
Module	Indoor	Secondary school students	STS	Attitude towards biotechnology	Klop, Severiens, Knippels, Van Mil &Ten Dam(2010)
Animated online learning, “BrainPoP Model”.	VLE	Secondary school students	ICT	Technological literacy; non-routine problem solving skills	Rosen (2009)
Electronic note-taking	Indoor	Grade 9 secondary	ICT	Student engagement in lesson;no	Duhon(2015)

		school Students		significance in academic improvement; scientific process; inquiry-based learning	
Cooperative learning	Indoor	Secondary - school students		Effective communication skills	Parveen & Batool(2012)
Learning workshop via video teleconferencing and virtual laboratory, “School-Scientist Partnership Model”	Combination of case study & virtual laboratory	Secondary school students aged 13	STS	Effective communication skills	Falloon (2012)
Learning workshop about Environment in the nature	Outdoor	Secondary school students	STS	Effective communication skills; society & civic responsibility	Mohd Wahid, Rusli, Azlan, Tamby & Lilia(2013)
Project-based learning	indoor	Grade 9 students	STS	Effective communicative skills, inquiry-based learning	Nurlaely, Permanasari & Riandi (2017)
3D visual molecule dynamics of protein	indoor	Grade 9 & 10 students	-	Technological literacy	Burgin, Oramous, Kaminski, Stocker & Moradi(2018)
Jmol (software visualization of molecular structures)	indoor	Grade 11 students	-	Technological literacy	Levkovich & Yarden(2017)
Problem-based learning	indoor	Grade 9 students	-	Inquiry-based learning	Jefriadi, Ahda & Sumarmin (2018)
Hands-on activity (patterns of genetics inheritance)	indoor	Grade 12 students	-	Effective communicative skills	Finch & Vieira(2018)
Biology cloud experimentation on phototaxic Euglena cells	indoor	Grade 7 & 8 students	-	Scientific inquiry	Hossain et al.(2016)

Notes: HOTS-Higher order thinking skills; ICT-Information Communication Technology; STEM-Science, Technology, Engineering & Mathematics; STS-Science, Technology & Society; VLE-Virtual learning environment

6. Discussion

The results of this study showed that researchers began to show interest in biotechnology teaching in secondary school since 1998.When we looked back into the year of 1953, James D. Watson and Francis Click described the structure of DNA which started the revolution of biotechnology (Mathews & Van Holde, 1996; Biotechnology Innovation Organization, 2016). It was not until 1990s when researchers in sciences in general and social sciences in particular saw the need to include biotechnology and biochemistry in school curriculum seriously. Professor John G.Wells and his fellow researchers have been working hard to promote the rationale of biotechnology inclusion in technology education since the 1990s (Wells, 1994;Wells, 1999; Dunham et al.,2002; Kwon, 2009; Wells & Kwon, 2009). In the year of 1997, British scientists, led by Ian Wilmut, from the Roslin Institute, Scotland, reported the cloning of

Dolly, the sheep using DNA from two adult sheep cells. In 2002, rice becomes the first crop to have its genome decoded. In 2003, the Human Genome Project is completed, providing information of the locations and sequence of human genes on all 46 chromosomes (Biotechnology Institute of Washington, 2016; Biotechnology Innovation Organization, 2016). These three events motivated and propelled social scientists to promote the rationale to include biotechnology in school curriculum.

From this study, the use of module and online learning had been the most favourable instructional practice to teach biotechnology in school. Biology is considered a difficult subject since there are many complicated biological processes about life and its interaction with environment (Wan & Zanaton, 2014). In the past, the focus in class was rote memorization, teacher-centered lessons and conduct laboratory works with cookbook guidelines that did not motivate secondary school students to study science subjects (Bonde et al., 2014). Moreover, the lacking of pedagogical content knowledge among the teachers and the lacking of course manual and module in biotechnology have to be considered (Rashidah et al., 2014; Wan & Zanaton, 2014). Therefore, a module could be used as a resource, a reference to assist the teachers and students to learn project-based learning.

In science and biology education, the information communication technology increasingly became an important element in holistic and integrated teaching. The animation-based online learning has a high potential to enhance students' understanding and learning motivation. The teachers acted like the mediators in the learning process. The psychological-educational dimensions of teaching and learning with animations lead to construction of knowledge transfer ability (Rosen, 2009). Besides that, more and more free and open accessed learning platform have been available in the the virtual world. For instance, the Virtual Science Hub (ViSH) provided scientists, teachers and their pupils a package of activities, materials and tools for enabling the integration of e-infrastructures into school curricula (Barra, Gordillo & Quemado, 2014). The Virtual Science Hub (ViSH) could provide e-infrastructure resources as content units that can be individually adapted and integrated into existing teaching materials and curricula of teachers (Barra et al.,2014).

Game-based activities have since gain popularity in teaching and learning. Games and learning can be successfully developed and implemented in the learning environment by combining both game design and instructional design approaches (Syamsul & Norshuhada, 2010). A gamified laboratory simulation, "Labster" can significantly increase both learning outcomes and motivation levels compared to traditional teaching (Bonde et al., 2014). Currently, simulations and games are used sporadically in biotechnology education as institutions still focused on delivering instructions. To fully explore the potential of gamified simulation in biochnology education, policymakers and end users, researchers and companies must work together to develop new gamified simulations to reap benefits of modern technology for the improvement of science education.

The field experiences provide a range of learning opportunities that laboratory cannot supply. If a workshop about environmental biotechnology and ecology is carried out in the field, the students will be placed in the real world as they can observe the nature themselves. They can explore the plants such as lichen themselves (Mohd Wahid et al., 2013). The workshop could also be conducted in the hall. The school may attach itself to the universities and research institutes to collaborate the exchanges of new knowledge in biotechnology. According to Falloon (2012), a series of video-conferencing teaching workshop and virtual laboratory, which formed a component of a school-scientist partnership was effective as an interactive medium for developing content knowledge among students. However, it was also expensive and time-consuming.

From this study, the authors found that arts and drawing could stimulate the students' verbalization about scientific activities (Lannes et al., 1998). Comics could be used as a pedagogic tool. Comics are pictorial images and graphics juxtaposed in a deliberate sequence destined to transmit information to produce an answer for the reader. The association between fiction and comics stimulated the students' imagination. The teachers in general considered the use of science fiction and comics as a very effective tool for teaching biotechnology (Rota & Izquierdo, 2003).

The authors also found that it was suggested that biotechnology could be integrated into English language teaching when teachers wanted to teach issues related to biotechnology. According to Hohenshell et al. (2004), writing was instrumental in learning difficult concepts in biotechnology. Written work provides a record of understanding. Students explained biotechnology concepts to a real-life audience. Before they could do the explanation, they are compelled to use simple language to construct their own understanding. As emphasized by Moore (1994), writing is important for success in biology. Therefore, teachers must teach students to write effectively.

From this study, the authors also found that cooperative learning is still one of the appropriate ways to teach biotechnology. Cooperative learning occurs in classrooms where students work in small groups on learning activities (Ornstein, Pajak & Ornstein, 2011; Ornstein & Hunkins, 2013) Cooperative learning could involve laboratory work, group discussion and other activities where students find their ways to the answers. It is a more effective way than traditional teacher-centered teaching in science.

Laboratory work based on active learning could provide a meaningful learning for students (Taraban et al., 2007) The active learning-based laboratory units designed and developed collaboratively by high school teachers and university faculty could lead to increased use of student-centered instructional practices as well as enhanced content knowledge and process learning for their students.

Modeling Instruction is an effective model for science education. Modeling Instruction program places an emphasis on the construction and application of conceptual models of physical phenomena as a central aspect of learning and doing science (Hestenes, 1987; Jackson et al., 2008). Modeling Instruction produces students who engage intelligently in public discourse and debate about matters of scientific and technical concern. Students could confidently debate the controversial topics like cloning or genetically modified organisms in biotechnology. In modeling instruction, the first stage is to establish understanding of a question to be asked through a demonstration and class discussion. Then, in small groups, students collaborate in planning and conducting experiments to answer the question. The students present their conclusions. Next, the students applied their newly-discovered model to new situations to refine and deepen their understanding. Students work on challenging worksheet problems in small groups, and then present and defend their results to the class.

The overall results from this review showed that teachers still preferred indoor activities compared to outdoor activities. The studies that conducted in the room including 2 case studies, 1 laboratory assignment and 7 activities using virtual learning environment (VLE). The only outdoor activity carried out outside the classroom was the learning workshop related to the environment topics. The setting that decided by the teachers was related to the purpose of the learning topics. For instance, if the learning topic related to some non-routine activities, teachers would prefer the assistance of technology such as virtual learning platform to describe the abstract concepts to the students. When the topics related to daily issues, teachers preferred science-technology-society model (STS) to teach the students in class. Besides, biotechnology teaching could be integrated with subjects such as English language and art to teach students about the abstract concepts in biotechnology which were not easy for the teacher to explain verbally.

There were three integrative models mainly used by the teachers when they taught biotechnology; Science-Technology-Society model (STS), biotechnology lesson integrated with information communication and technology (ICT) and STEM research process. Science-Technology-Society model (STS) is based on ideas of incorporating social, cultural, environmental, political an ethical aspect into the curriculum (Pedretti, 2002). STS curriculum incorporates into the learning materials issues such as genetic engineering, genetic testing, genetically modified foods, stem cell research, climate changes and sustainable development. Socio-scientific issues can serve as the organizers for science education and pose many advantages in using them. These issues allowed further inquiry, encourage the search for new information, represent examples for interdisciplinary topics, and foster the emergence of continuous discourse (Hughes, 2000). Besides, the students are expected to apply moral reasoning and critical skills while acting towards the improvement of their environment. Incorporating controversial issues such as, cloning and genetic modified food and science and technology conflicts is also a recommended method for enhancing students' interest, motivation and improving their system thinking (Chen & Stroup, 1993). Furthermore, teachers and students can acquire both intellectual and ethical skills, which are instrumental in perceiving the political and social forces that drive scientific and technological development when they applied the STS approach in class.

Biotechnology lesson integrated with information communication and technology (ICT) is another favourable integrative model preferred by teachers. The concepts of biotechnology are mainly abstract to our students. The concepts of biotechnology is hardly described in the daily life of the students. As internet protocol desktop systems, Web 2.0 video based collaborative tools and high speed data networks become commonplace, using ICT to synchronously connect students to knowledge and experience worldwide will become a viable option for many teachers. The teachers may use the ICT tools such as advanced organizer and YouTube to explain the concepts of biotechnology more explicitly to the students. The ICT-based approaches also provide an opportunity for increasing the skill level of students and motivate young people to pursue studies within the STEM (Science, Technology, Engineering & Mathematics) fields (Bonde et al., 2014). According to Vebrianto, Kamisah & Lee (2012), information communication and technology (ICT) is raising the bar on the competencies needed to succeed in the 21st Century.

Compared to Science-Technology-Society model (STS) and biotechnology lesson integrated with information communication and technology (ICT), STEM research process is seldom applicable in biotechnology teaching although it is another effective way to teach biotechnology. STEM research process refers to experiment conducted to solve problems in STEM (Science, Technology, Engineering & Mathematics) fields. In STEM research process, inquiry-based scientific process is used to assist students to understand the natural phenomena (Harland, 2011).The integrative of STEM disciplines will foster the scientific inquiry that emphasize on the students questioning, data collection, explanation and presentation of the results found in the research (Bryan, Moore, Johnson & Roehrig, 2016).Engineer, scientist and mathematician always use the engineering design and scientific inquiry routinely to solve the real-world problems (Sanders, 2009).They used to conduct experiments to test the hypothesis and make conclusions. Besides, the integrative of STEM disciplines provides opportunities for the K-12 students to build on their 21st century skills such as cognitive skills, intra-personal and interpersonal skills and the abilities to secure a job in the near future (Bryan et al. 2016). In order to prepare students to meet the challenges in 21st century skills, teachers must instil and cultivate the skills in their lessons.

In 21st century, our children live in a global, digital world. Many of today's youngsters are comfortable using laptops, instant messaging, chat rooms and cell phones to connect to friends, family and expects in local communities and around the globe.Given the rapid rate of change, the vast amount of information to be managed, and the influence of technology on life in general, students need to acquire different, evolving skills sets to cope and to thrive in this changing society(NRCEL & Metiri Group, 2003).According to NRCEL & Metiri Group (2003), 21st century skills involved digital-age literacy, inventive thinking, effective communication and high productivity.

In this study, the authors found that many of the approaches used to teach biotechnology promoted 21st century skills such scientific and technological literacy, basic literacy, multicultural literacy and language which is essence to digital-age literacy. When teachers use ICT in their lessons, students must have knowledge what technology is, how it works, what purpose it can serve, and how it can be used efficiently and effectively to achieve their learning goals. For teachers who used laboratory kit or conducted laboratory in virtual environment, science process skills and scientific literacy were synchronously helping the students to understand the knowledge and master the skills. According to NCREL & Metiri Group (2003), students with scientific literacy knowledge and understanding of science concepts and processes required to engage in the digital era society. Students can ask questions, get or determine answers from daily experiences. Then they have the ability to describe and explain the natural phenomena. Students also can assess the quality of scientific information on the sources and methods used to produce it. In the other end, science process skills help students to progress from concrete thinking levels to more complex thinking levels that promotes higher order thinking skills in 21st century skills. Through hand-on activities like experiment, students use different senses such as touching, observing and listening in controlled manner. With good communication skills, students will be able to describe the natural phenomena in science class.

The authors also found that inventive skills are instilled in the modelling instruction approach. The elements in inventive thinking involved adapt and manage complexity, self-direction, curiosity, creativity, risk taking, higher order thinking and sound reasoning (NCREL & Metiri Group, 2003). Inventive skills are one of important components in 21st century skills that encourage students to think critically, examine problems, gather information, collaboration communication, creativity and innovation required for success in their future.

The other learning outcome that related to 21st century skills is effective communication. Effective communication including teaming and collaboration, interpersonal skills, personal responsibility, social and civic responsibility and interactive communication (NCREL & Metiri Group, 2003). During the learning process, students cooperatively interact with others to solve problems. They also need to manage their own behaviours and emotions when interacting with others. They will also demonstrate their in-depth knowledge and responsibility before they exchange information through communication tools. Beside the inculcation of 21st century skills, the use of inquiry-based learning and non-routine problem solving skills also generate positive attitude among the students towards biotechnology.

7. Conclusion

The findings of this study showed that module combined with e-learning is a possible option for instructional in biotechnology teaching in secondary school. It may possible enhance the practice with the inclusion of virtual-learning and game-based activities. Most of the approaches are study-centered learning where students engagement in learning is a foremost concern. The findings of this study also implied that there is a need for increasing further empirical research on the practices of biotechnology teaching in secondary school. There might be some fugitive literature and closed reports that could further give the researchers more insight about the instructional practices in biotechnology teaching.

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