

Effect of structured inquiry-based laboratory on thinking skills among biology students

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ABSTRACT

This study aimed to investigate thinking skills practical achievement tests between Biology students who perform Structured Inquiry-based laboratory (SIL) and students who do not (TT) (only traditional teaching in classroom). Two groups of co-ed Form 4 Biology students (n=64) from two public schools in Kuala Lumpur, Malaysia were selected for the study. Lower-order thinking skills (LOTS) questionnaires about practical were tested in the pre-test and post-test. A curiosity index model (as covariate) which was developed by Ainely (1987) (cited by Fulcher, 2004) was used to investigate levels of the curiosity prior the experiment started due to curiosity might affect the behavior being observed. The Curiosity Index analysis, TT students had higher level of curiosity than SIL students but no significant differences. TT groups also exhibited higher Breadth and Depth levels of curiosity than the SIL, with no significant difference shown. The students who were exposed to SIL achieved significant higher LOTS post-test mean score than TT group with a small effect size (partial eta squared) of .16. This paper suggested that students' thinking skills can be nurtured with the suitable types of instructional method. Even though highly curious students tend to explore their surroundings, but without the implementation of proper instructional methods and techniques by their teachers to continuously inspire their curiosity, it is difficult for them to acquire higher level thinking skills.

Keywords:

Curiosity level
Structured inquiry-based
laboratory
Malaysia

Introduction

The biology of the 21st century will see the emergence of biologists adept in a multitude of competencies to be on the forefront of innovative trends, *'The New Biologist is not a scientist who knows a little bit about all disciplines, but a scientist with deep knowledge in one discipline and a "working fluency" in several'* (National Research Council, 2009, p. 20). A paramount statement that necessitates large-scale efforts if a new generation of these biologists is to be realised. For example, only about 45,938 (38%) Malaysia students who studied in STEM fields, out of 122,912 total graduates, graduated from public universities according to Malaysia Education Statistics Education Planning and Research Division 2016 (Ministry of Education Malaysia, 2016). The number is still far away from the policy 60:40 Science: Art students which has been targeted by Ministry of Education Malaysia which had been written inside the educational blueprint. It is a strong wish for new generations to involve themselves in 21st STEM world (Kamarudin, Hamza, & Lee, 2016). But first, Biology students should equip themselves with critical-thinking skills in order to discover more new issues in science and solve problems using science technology.

Thinking is defined as *'the systematic transformation of mental representations of knowledge to characterize actual or possible states of the world, often in service of goals'* (p.2) (Holyoak & Morrison, 2005). Thinking may revolve around its physical aspect or in an abstract form such as memorising, recalling some facts, making observation, judgment, making assumption, evaluation, make decisions, sharing different ideas, arousing curiosity, visualizing, inquiring and refining (Miller & Stoeckel, 2016).

Bloom's revised taxonomy proposed six thinking skills from lower-order to higher-order thinking skills: 1) Memorising 2) Understanding 3) Applying 4) Analysing 5) Evaluating 6) Creating (RIC, 2006). Researchers were using Bloom's thinking skills as a guideline in instructional approaches (e.g. inquiry teaching, computer-assisted, problem-based learning, context-based approach) to improve learners' thinking skills (Avargil, Herscovitz, & Dori, 2011; Friedel et al., 2008; Niu, Behar-Horenstein, & Garvan, 2013; Saadé, Morin, & Thomas, 2012). Teaching thinking skills become a difficult or complex task for educators where some knowledge is needed to be able to design, or create the proper modules or activities for a certain level of higher order thinking to be achieved and to enable a learner to practise it (Smith, 2002).

Laboratory activities are one of the avenues to enable students to learn thinking skills more comprehensively and significantly at all levels of science education. The

cookbook laboratory approach is basically a teacher- and textbook-centred instructional; students go through step-by-step instructions from the book and 'black and white' answers are provided, with little room for raising questions or exchanges of ideas about the experiment's answers (Hutchins & Friedrichsen, 2012; Johnson, Zhang, Kahle, & Broomfield, 2012). On the other hand, the inquiry-based laboratory approach is more student-centred with active learning which gives rise to newfound abilities as learners apply what they learn in the real world (Brickman et al., 2009; Voogt, Tilya, & Akker, 2009). Students who practise the inquiry-based approach have often been found to explore interactions in more details than non-inquiry students.

Nonetheless, a student with inquiry should have these criteria: able to ask relevant questions, form hypotheses, conduct investigation based on choosing the right research questions, carry out experiment planning, conduct the experiment, and lastly able to analyse the findings and make conclusions (Dkeidek et al., 2012). Sometimes, these inquiry criteria may need some assistance from a teacher who is able to delivery inquiry-based instructions effectively. Every teacher interprets inquiry differently and a teacher's guidance and instructions can be based after highly structured and teacher-centred approaches to open inquiry or just simply getting tools in hands type of inquiry (Dkeidek et al., 2012; Hofstein & Mamlok-Naaman, 2007). Inquiry approaches are student-centred, with students conducting an investigation and finding the answer for scientific questions (Johnson et al., 2012). More research is required to investigate the effectiveness of different approaches for science teachers' development by providing teachers with skills to implement student-centred instructional techniques in inquiry-type experiences instead of just relying on general learning in the science laboratory (Hofstein et al., 2005).

Curiosity is defined by Berlyne & Walker (1978) as *'an internal state occasioned when subjective uncertainty generates a tendency to engage in exploratory behavior aimed at resolving or partially mitigating the uncertainty'* (p.98). Many phenomena spark a person's curiosity at different levels either naturally or aroused various actions such as when doing scientific exploration, engaging in a supernatural scene, solving puzzles, observing sports or trying to solve any unexplained and mystery murder cases (Borowske, 2005). External environment factors that can arouse a person's curiosity may include classroom facilities, curriculum pedagogy, technology, teaching model and others (Arangala, 2013; Arnone, Small, Chauncey, & McKenna, 2011b; Arnone, 2003; Gottlieb, Oudeyer, Lopes, & Baranes, 2013; Litman & Jimerson, 2004; Pica, 2005). Students with high curiosity were reported to perform better on national academic achievement

tests than students with lesser curiosity when the school is able to facilitate them with a challenging learning environment (Kashdan & Yuen, 2007). Due to that, curiosity had become one of the major extraneous variables in this study, and two samples that being selected should have no significant different for their curiosity level at the beginning of the research.

Purpose

The purpose of this study was to compare if students correspond with the thinking skills achievement tests between students who perform Structured Inquiry-based laboratory (SIL) and students who do not (TT) (only traditional teaching in classroom) using two secondary school Biology chapters. The specific research question was:

What is the difference between the thinking skills test scores of biology concepts of students experiencing Structured Inquiry-based laboratory (SIL) and the students relying on traditional teaching (TT) alone?

Methodology

This study used quasi-experiment method and employed a pre-test-post-test design was used to investigate the research questions mentioned above. The content validity of the pretest and posttest was examined by two experienced teachers. Items were discussed with the teachers in the content area and their suggestions were used to determine validity of the instruments after confirmed the content of the test was suitable.

Subjects

Two groups of co-ed Form 4 students (n=64) from two public schools in Kuala Lumpur, Malaysia were selected for the study. Both groups possessed similar academic results in biology. Due to reduce the effect of extraneous variable in this study, curiosity level was also been tested so that the groups that been chosen had similar curiosity level.

Instruments

Curiosity

A curiosity index model which was developed by Ainely (1987) (cited by Fulcher, 2004) (Bahadir & Certel, 2013) was used to investigate levels of the curiosity in the two groups of students from different schools. The index has two subscales called Breadth and Depth, totaling 47 items. The Breadth scale consists of 27 items (items 6, 7, 8, 10, 11, 12, 14, 16, 19, 21, 22, 23, 24, 25, 28, 29, 30, 34, 36, 39, 40, 41, 42, 43, 44, 45 and 46) and the Depth scale consists of 20 items (1, 2, 3, 4, 5, 9, 13, 15, 17, 18, 20, 26, 27, 31, 32, 33, 35, 37, 38 and

47). Students showed their agreement for Breadth and Depth item by using a 6 point likert-type index. 1. 'Completely Agree', 2. 'Mostly Agree', 3. 'Slightly Agree', 4. 'Slightly Disagree', 5. 'Mostly Disagree', 6. 'Completely Disagree'. It is determined that the minimum score obtained of in the index is 47 (47x1), and the maximum score is 282 (47x6). All positively worded items were reverse coded so that higher scores reflect higher curiosity level. Items 24, 37, 39 and 44 were not reverse coded due to them being negatively worded with respect to curiosity.

Thinking Skills Test

In this study, lower-order thinking skills (LOTS) (e.g. Bloom's action verbs such as *list, state, record, describe*) questionnaires were tested in the pre-test and post-test. The questions were adapted from the Malaysian Certificate Education Biology Paper 3 past year's questions based on the Bloom taxonomy (1956) suggested. Students' answers were marked by the researcher for consistency fair marking. The pre-test was conducted to identify the students' existing biology level of the two topics: 1) Movement of substances across the plasma membrane and 2) Chemical composition of the cell (enzyme). The post-test was administered to identify the level of students' thinking skills after the two classes had gone through the experimental treatment. Sufficiency of time for the students to answer all the thinking skills questions and deliberate over any probable confusing written instructions was the major concerns in the pilot test.

Treatment

The biology content and objectives of the SIL and TT groups were the same and were based on the curriculum of the Curriculum Development Centre, Ministry of Education Malaysia (Curriculum Development Centre Ministry of Education Malaysia, 2005). Both classes were exposed to eight weeks of teaching, one week covering four periods, 35-minutes per period. The lesson was conducted by their own respective subject teachers in schools. Both instructions were in dual language (English and *Bahasa Malaysia*).

Traditional Teaching (TT) group

For the TT group (n=28), students with no laboratory practices used all of the four periods per week for the Biology classroom teaching. According to the lesson plan that prepared by the researcher to the teacher for execution, the teacher delivered direct learning to the group. The whole class was put together as a group with lecture notes being delivered through power point slides. After discussing concepts with the teacher and having

given explanation, the students answered questions posted by the teacher. Overall, TT group underwent a direct or a more theory-based instructional method throughout the teaching period by having class discussion with the usual explanation and answers given by the teacher.

Structured Inquiry-based laboratory (SIL) group

The SIL group students were given classroom teaching aided with laboratory practices during the treatment. 24 periods of lecture classes and four laboratory practicals (4x2= 8 periods) were conducted for the group. On top of receiving the same method as the TT group, their classes were laboratory-aided in the practical periods. Four subtopics were chosen for their hands-on practical classes. Teachers conducting the inquiry laboratory based on the lesson plan that prepared by the researcher. The students chose their own classmates and they formed groups of four persons. Only one set of apparatus was given to each of the group during the laboratory practices.

A week before the laboratory class began, the teacher requested the lab assistant to prepare all the apparatus and materials. The students and the teachers had a discussion on the experiments' objectives, research questions, hypotheses, planning and procedures during lecture time in the classroom.

During the practical class, the teacher took about 5 minutes to brief the students about the experiment. Students were given 45 minutes to finish the experiment. Each student was required to do the experiment at least one time on their own to have the replication results. The replication of an experiment not only gives assurance on the reliability of the outcomes, but also solves the problem often faced by secondary schools today, where students complain about the shortage of apparatus and materials for each of them to conduct experiments. Hence, with this approach, each student was able to experience scientific skills instead of just being an observer during class, thus effective laboratory management can be achieved by the teacher.

Replication results were recorded and gathered from each of the students in the group after having conducted the experiment. Then the teacher took about 5-10 minutes to discuss the results and conclusion with the students before the class ended for the day.

Results and Findings

Lower-order Thinking Skills

The results of the ANCOVA and descriptive data analysis on students' LOTS post-test scores for SIL and TT groups are shown in Table 1. The table showed that there was a significant difference between the LOTS post-

test mean scores of SIL group (M=10.22, SD= 3.18) and the scores of the students who were using TT method (M=7.75, SD = 1.92); $F(1,61) = 11.51, p = .001, p < .05$, with effect size (partial eta square) = .16.

Evidently, the students who were exposed to SIL achieved a higher LOTS post-test mean score than those who were exposed to TT instructional method. A small effect size (partial eta squared) of .16 (Cohen's 1988) suggests that 16% of the variance in the LOTS post-test scores were related to the differences in the instructional methods.

Table 1. Summary of ANCOVA on students' LOTS post-test scores of students in LP and TT groups

Class	Mean	SD	N	F	Sig.	Eta-square
SIL	10.22	3.181	36	11.507	.001	.159
TT	7.75	1.917	28			

Table 2 showed that there was no significant relationship between the pre-test LOTS mean score and the post-test LOTS mean score, $F(1,61) = 2.32, p > .05$ with effect size of .037.

Table 2. Summary of Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	112.846 ^a	2	56.423	7.878	.001	.205
Intercept	541.673	1	541.673	75.630	.000	.554
LOTS_Pre	16.584	1	16.584	2.316	.133	.037
Group (method)	82.415	1	82.415	11.507	.001	.159
Error	436.888	61	7.162			
Total	5897.000	64				
Corrected Total	549.734	63				

Discussion

This study showed a stark improvement of students who practiced laboratory where they performed better in thinking skills on biology concepts over students who did not. Students in the SIL group performed better in their post-test compared to the students in the TT treatment. Deciphering the data obtained from this study, it appears that inquiry instructional contributed towards students' thinking skills.

This study had showed that students who practiced inquiry laboratory skills did give better results with their thinking skills (lower-order). Fostering student's thinking skills with inquiry laboratory practices can be applicable to different curiosity levels of Biology students. Undeniable curiosity plays an important factor in developing a student's inquiry into scientific

phenomenon. This study showed that type of instructional is more important than just to have natural curiosity in enhancing students' thinking skills. Basically, inquiry needed students to describe materials, observe their surrounding, ask questions, making hypothesis, collect and analyze data, develop scientific principles, construct explanation and communicate their findings with others (Opara, 2011). A well-planned laboratory should be setup in this way so that can motivate students active learning. Thus, proper physical apparatus and psychosocial factors shall affect students' thinking skills (Osman, Ahmad & Halim, 2011). In laboratory, when students work in groups, they are given a chance to communicate with the peers, translate the knowledge among themselves and filling the gap of knowledge between stronger and weaker students. All these activities are said to be able to enhance their thinking skills from lower order to higher order (Walton & Baker, 2009; Deacon & Hajek, 2010). Teachers who emphasize group work, as can be seen in this study, are more likely to cause an increase of communication and interaction among the students, which opens up the door to more engaging scientific arguments during the laboratory practices. The peer discussions gave themselves the chances of allow for the sharing of individual ideas, findings, and solutions, resulting in arousal of their curiosity to fill their knowledge gap they had.

Hence, it is important to keep the students highly motivated with such methods on top of sustainable knowledge and skills in order to produce quality science graduates, as aspired in Vision 2020 to meet the nation's human capital targets and help the country perpetuate talents on a sustainable basis.

Conclusion

This study had shown a significant and promising outcomes of the value of using inquiry laboratory practices in the teaching biology. Although almost everyone has a natural sense of curiosity, they differ according to the topic of interest. Highly curious students tend to explore their surroundings, but without the implementation of proper instructional methods and techniques by their teachers to continuously inspire their curiosity, it is difficult for them to acquire higher level thinking skills. It is interesting to note that the study gives us some telling insights as to how effective inquiry laboratory practices affects students in scientific inquiry, performing experiments, recognising the apparatus and materials, data collection, data interpretation, teamwork discussions, and cooperative learning. This in turn may serve teachers or educators well if they adopt and practise a similar curriculum setting. The laboratory practices may help the students to improve their thinking

skills, feel at ease absorbing biology lessons and with the accumulated confidence, they shall achieve better academic results in content of science.

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Think-Pair-Share Cooperative instructional strategy is an instructional strategy that develops the thinking ability of students, erodes shyness, promotes gender equality, peaceful co-existence and greater student involvement. among others (Australian Catholic University Resource- ACU, 2012); Carin and Sunds (1975 p.10). The aim of this study was to determine the effects of Guided Inquiry and Cooperative Instructional Strategies on the academic achievement of SS1 students in the concepts of photosynthesis. Specifically, the study sought to: 1) Determine the effects of Guided Inquiry Instructional Strategy (GIIS), Cooperative Instructional Strategy. Undergraduate Biology Lab Courses: Comparing the Impact of Traditionally Based "Cookbook" and Authentic Research-Based Courses on Student Lab Experiences. By Sara E. Brownell, Matthew J. Kloser, Tadashi Fukami, and Rich Shavelson. This study compares a cookbook-type laboratory course to a research-based undergraduate biology laboratory course at a Research 1 institution. The research-based lab course had several hallmarks of authentic research: a single longitudinal research focus, research questions with currently unknown answers, student-determined experimental designs, and collaboration among lab peers. Twenty students in the research-based lab were matched with 20 students in the cookbook lab on the basis of five demographic characteristics. However, inquiry-based science instruction does not automatically translate into increased student achievement on tests. Hung (2010) used structured equation modeling on data from over 9,000 students on the Trend in International Mathematics and Science Study 2003 (Martin, Mullis & Chrostowski, 2004). He found that inquiry-based science instruction had only a small direct impact on achievement and that positive student attitudes toward science raised achievement more. Hung (2010) suggested the positive impact of inquiry strategies on student attitude could indirectly affect achievement. Overall, among educational institutions in the United States, the lecture and laboratory course are co-requisites for students enrolled in a first-year general chemistry course. However, there are some chemistry courses that do not have a co-requisite laboratory component. In order to understand what effect the laboratory component of the course has on student learning, student attitude towards general chemistry, the logical thinking skills and problem solving abilities of students, both quantitative and qualitative data was collected for this mixed methods study. Chapter Three is on the implementation of student roles in guided-inquiry based SWH laboratories. Inquiry-based instructional approaches may benefit students' thinking skills by In structured inquiry, students investigate a teacher-formulated question through a prescribed procedure. Research also demonstrates great enthusiasm among students regarding the integration of lab assignments with an inquiry approach (Garnett et al. 1995; Hofstein et al. 2001). According to Hsiao-Lin et al.