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Discovery learning is an approach that encourages students to become active participants in the learning process by exploring concepts and answering questions through experience. It is one of several inquiry-based learning techniques that seems particularly suited to the instruction of science since performing experiments is one of the key methods in discovery learning. However, the efficacy of discovery learning projects have not been explored much in Malaysia. In this study, an experiment integrated with real-world biotechnology industry example focusing on the function of the enzyme pectinase in the clarification of fruit (apple) juice was adapted and introduced to a group of urban, international secondary school science students who had undergone prior direct instructional guidance on the biological role and function of enzymes. The students were asked to complete a set of pre-experiment and post-experiment questions in order to analyse the impact of the experiment on their understanding of this topic. Results suggest that this discovery learning project do strengthen the learners' prior knowledge and understanding of the function of biological enzymes through application of concept based on real world practice. High level of positive feedback was received (86.2%), with the students commenting on the "fun aspect", being excited about being able to perform the experiment and expanding their understanding by linking their findings with a real-world, industrial application. Given the reported steady decline of Malaysian students enrolled in STEM (Science, Technology, Engineering and Mathematics) courses at secondary and tertiary levels, our findings suggest that developing and including more real-world, discovery type projects in secondary schools may help to effectively raise student interests in science subjects such as biology through new learning approaches.

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Abstract

Discovery learning is an approach that encourages students to become active participants in the learning process by exploring concepts and answering questions through experience. It is one of several inquiry-based learning techniques that seems particularly suited to the instruction of science since performing experiments is one of the key methods in discovery learning. However, the efficacy of discovery learning projects have not been explored much in Malaysia. In this study, an experiment integrated with real-world biotechnology industry example focusing on the function of the enzyme pectinase in the clarification of fruit (apple) juice was adapted and introduced to a group of urban, international secondary school science students who had undergone prior direct instructional guidance on the biological role and function of enzymes. The students were asked to complete a set of pre-experiment and post-experiment questions in order to analyse the impact of the experiment on their understanding of this topic. Results suggest that this discovery learning project do strengthen the learners' prior knowledge and understanding of the function of biological enzymes through application of concept based on real world practice. High level of positive feedback was received (86.2%), with the students commenting on the "fun aspect", being excited about being able to perform the experiment and expanding their understanding by linking their findings with a real-world, industrial application. Given the reported steady decline of Malaysian students enrolled in STEM (Science, Technology, Engineering and Mathematics) courses at secondary and tertiary levels, our findings suggest that developing and including more real-world, discovery type projects in secondary schools may help to effectively raise student interests in science subjects such as biology through new learning approaches.

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1. Introduction

Many reviews have been performed in the past few decades on the teaching and learning of science subjects, resulting in recommendations to adopt more active learning, student-centered learning approaches to actively engage students in the learning process with the major aim to create more long lasting, meaningful learning (Michael 2006 and references therein). Indeed, an increased trend has been noted with the supplementation (and even replacement) of conventional direct/explicit instruction with more constructivist-based approaches (Alfieri et al. 2011), such as the American Association for the Advancement of Science (AAAS, 1993) and the National Research Council (NRC, 1996) endorsement of a science curricula that actively engage science students by using an inquiry-based approach (Gibson and Chase 2002). Constructivist-based approaches focus on less guidance but more engagement to encourage learners to participate, discover and construct their own knowledge (Michael 2006; Alfieri et al. 2011).

Discovery learning is one of several inquiry-based learning techniques that seems particularly suited to the instruction of science, more closely aligned with concepts of exploration, discovery, and invention. Hodson (1990) suggested that inquiry-based learning was a more effective way for students to learn science. Performing experiments (e.g. practicals, research projects) are an integral part of science subjects such as Biology where learners acquire specialized knowledge and skills through participation and observation. Students are provided with ample opportunities to notice patterns and discover underlying causalities/explanations during their practice of interacting with materials, manipulating variables, exploring phenomena and applying concepts/principles (Alfieri et al. 2011), which are indeed embedded as the learning outcomes of many science practical sessions. The learner is expected to discover the target information within the confines of the task and its material (Alfieri et al. 2011).

Koksal and Berberoglu (2014) found a significant effect of guided discovery approach on students' achievement in science. Several studies investigated and also reported the positive effect of guided discovery approach on students' achievement in specific science subjects such as chemistry, physics, mathematics and biology (Inuwa et al. 2016 and references therein). In fact, it was reported that students who learn science using an inquiry approach scored higher on science achievement tests, have improved science process skills, and have more positive attitudes towards science when compared to students taught using a traditional approach (Gibson and Chase 2002 and references therein). However, pedagogical and cognitive concerns have questioned the efficacy and limitations of discovery learning approaches, especially on the amount of guidance or support provided to the learners (Klahr and Nigam, 2004; Mayer, 2004; Kirschner et al. 2006; Sweller et al. 2007).

In a lower-division biology course, better student test performance on questions related to topics incorporating some discovery learning was observed when compared with topics learned in lecture (Wilke and Straits 2001). Ajewole (1991) and Oghenevwede (2010) found that guided discovery approach had significant effects on Nigerian students' achievement in biology. Positive effects of guided inquiry instruction on students' achievement and understanding of environmental biology was also observed by

Hasan (2012). Similarly, Conway (2014) reported that there was a statistically significant difference in the mean achievement scores of students in Biochemistry that were exposed to guided discovery approach compared to those taught using a conventional approach. However, a non-exhaustive search of current literature revealed only few studies related to inquiry or discovery learning in Malaysia, none of which focused on the effect of discovery approach in a science subject.

The aim of this small study was to explore the aspects of discovery learning that impacted learners' prior knowledge based on concept application within the context of an experiment integrated with real-world biotechnology industry example (biological function of the enzyme pectinase in apple juice clarification). Results provide a more evidence based approach on the positive impact of discovery learning on Malaysian students.

2. Methodology

Participants of this study were three cohorts (2016, 2017, 2018; total number of students was 61) of Year 10 (~16 years old) science students from a non-profit Cambridge International School offering the Cambridge curriculum in Kuala Lumpur. The discovery learning project consisted of an experiment integrated with real-world biotechnology industry example focusing on the function of the enzyme pectinase in apple juice clarification. The students had undergone prior direct instructional guidance (pre-requisite knowledge) on the biological role and function of enzymes. After a brief introductory talk on biotechnology (10 mins), the students were given the experiment handout to read (Apple fruit juice clarification, see Appendix 1) followed by a short practical briefing (5 mins).

Then, the students were asked to complete a set of five pre-experiment questions (Appendix 2) prior to the hands-on activities. Experimental activities were designed to illustrate the importance of two main factors (temperature and pH) on enzyme activities in apple juice clarification, while reinforcing content knowledge. Students were allocated 60 mins, working in two teams (~ 15-16 students per team) and left to independently organize, participate and perform the various tasks associated with the experiment. Upon completion of the experiment, the students were asked to complete a set of post-experiment questions comprising of the five pre-experiment questions (supplemented with experimental trigger questions) and an additional open-ended question relating to comments on this experience/experiment (Appendix 3).

Answers of the pre- and post-experiment questions were scored as part of the learning assessment with one mark awarded for each correctly answered question (Marking rubric, see Appendix 4). Descriptive statistics for overall total score and total score for each question pre- and post-experiment were determined using a paired T-test with the significant value set at $P < 0.05$ in Statistical Package for the Social Sciences (SPSS) v. 11.5 (IBM Corporation, United States of America). For test data where the distribution of the differences in the dependent variable between the two related groups were found to be not normally distributed, a non-parametric Wilcoxon-Signed test with significant value set at $P < 0.05$ was used to compare the two related groups. The number of positive, neutral, negative feedback types from the learners were also tabulated, and selected comments presented.

3. Results/ Findings

Students' performance pre- and post-experiment were evaluated to assess the impact of a discovery learning project towards the reinforcement of learners' knowledge. Results indicate significant improvements in overall total post-experiment scores compared to the pre-experiment scores for all three cohorts. Overall score increase ranged from 12.8% to 43.7% with p values of < 0.001, 0.003 and 0.001 respectively (Table 1). For individual questions that the students have prerequisite knowledge (Questions 2, 3, 4 and 5), variation in significant increase for post-experiment scores were observed among the three cohorts. A total of 1.125-, 4.3- and 8-folds higher post experiment scores were attained for Question 1 that suggests better understanding about Biotechnology after the introductory talk and discovery activity. Altogether, the experimental activity had strengthened the learners' prior knowledge as well as application of concept. Nevertheless, it is noted that a higher sample size is needed to further prove the effect (moderate effect size).

Table 1: Descriptive statistics of students' learning assessment

	Experiment		P value	Normality test	Wilcoxon-Signed test	Effect size	Interpretation
	Pre	Post					
Question 1	0.19 ± 0.40 0.08 ± 0.29 0.80 ± 0.37	0.81 ± 0.40 0.67 ± 0.49 0.90 ± 0.28	< 0.001 0.007 0.189	< 0.001 <0.005 -	< 0.001 0.014 -	0.745 0.707 0.387	Significant, effective Significant, effective Not significant
Question 2	0.82 ± 0.28 0.96 ± 0.14 1.00 ± 0.00	0.98 ± 0.09 1.00 ± 0.00 1.00 ± 0.00	0.002 0.330 -	< 0.001 - -	0.004 - -	0.519 - -	Some difference, larger size needed Not significant -
Question 3	0.77 ± 0.43 1.00 ± 0.00 1.00 ± 0.00	0.97 ± 0.18 1.00 ± 0.00 1.00 ± 0.00	0.031 - -	< 0.001 - -	0.034 - -	0.381 - -	Some difference, larger size needed Not significant -

Question 4	0.87 ± 0.34 1.00 ± 0.00 0.70 ± 0.37	0.84 ± 0.38 1.00 ± 0.00 0.93 ± 0.18	0.745 - 0.104	- - -	- - -	0.059 - 0.488	Not significant - Not significant
Question 5	0.35 ± 0.49 0.46 ± 0.50 0.67 ± 0.24	0.74 ± 0.44 0.92 ± 0.29 0.87 ± 0.35	0.001 0.039 0.111	< 0.001 < 0.001 -	0.001 0.046 -	0.576 0.577 0.440	Some difference, larger size needed Some difference, larger size needed Not significant
Overall score	3.02 ± 0.92 3.71 ± 0.69 4.17 ± 0.56	4.34 ± 0.62 4.58 ± 0.67 4.70 ± 0.65	< 0.001 0.003 0.001	0.001 0.001 0.293	< 0.001 < 0.010 -	0.801 0.740 1.033	Significant, effective Significant, effective Significant, effective

From the three cohorts of students, a total of 58 feedback comments were received (Q6 post-experiment) where 50 were positive comments (86.2%) regarding the experimental experience. There were eight neutral comments (13.8%) related to learning the reason for clear apple juice, industrial use of enzymes, biotechnology…*etc*. In particular, students commented on the fun aspect, were excited about being able to perform the experiment and linking their findings with a real-world, industrial application. Below are selections of the students' comments:

''Fun and educational"

"This workshop is helpful and fun. It does help us to expand our knowledge on enzymes and also biotechnology"

"It was very fun and entertaining experiment. It taught us to be responsible and accurate in our experiment…"

"The experiment was really fun and insightful. We got to see an actual process in industrial biotechnology"

"it was fun and a very good experience"

"knowledgeable, very fun"

"My understanding of enzyme activity has improved a lot through this experiment. I've also learnt ways in which enzymes are used to make daily use products"

"It was a very educational and fun experience. I would like to do this more often"

"I really enjoyed and I hope we can do more interesting experiments in the future"

"It was interesting and knowledgeable. I had loads of fun and I learned a lot. Please come back!!"

"I understand better about enzymes. More aware about biotechnology applications in our daily life. Fun Experience !!"
"It was nice and I gained a lot of knowledge from it"
"It was fun and a great experience…."
"Thank you. I appreciate the knowledge and I loved the experiment very much"
"It was fun and interesting and also informative"

5. Discussion

The positive influence of a discovery learning project on improving students' learning performance of a biological concept found in this small study is consistent with previous findings that reported the efficacy and significant positive effect of guided discovery approach on enhancing secondary school students' achievement for subjects such as chemistry, physics, biology and mathematics (Inuwa et al. 2016 and references therein). Other studies had also found that inquiry-based science activities not only had positive effects on middle and high school students' science achievement, but also contributed positively to cognitive development, laboratory skills, science process skills, and understanding of science knowledge as a whole when compared to students taught using a traditional approach (Gibson and Chase 2002 and references therein).

The many positive comments received on the experiment suggests an indirect positive impact of the discovery learning experience on students' attitudes and interest towards science. This also strongly agrees with past findings that students who used an inquiry approach have improved attitudes towards science compared to negative attitudes resulting from traditional methods (Gibson and Chase 2002 and references therein). Interestingly, a long term study found that a 2-week inquiry based summer science exploration program using an inquiry-based approach helped students maintain a more positive attitude towards science and a higher interest in science careers later (Gibson and Chase 2002). Certainly this context could be helpful in Malaysia, as it was recently reported that there has been a steady decline of Malaysian students enrolled in STEM (Science, Technology, Engineering and Mathematics) courses in secondary (Science stream) and tertiary levels. Only 21% of upper secondary school students chose to study science subjects in the year 2014, which is far from the 60:40 ratio of science to non-science students at upper secondary level target set by the country (Academy of Sciences Malaysia 2015).

5. Conclusion

This study found positive impacts of a discovery-based experiment on students' understanding of the function of biological enzymes through the application of concept using a real world example. More interestingly, a high level of motivation was detected from the feedback comments, showing that this discovery approach can generate a positive experience towards learning biology. Given the reported current decline of Malaysian students enrolled in STEM (Science, Technology, Engineering and Mathematics) courses, developing and doing more real-world, discovery type projects in secondary schools is recommended. Certainly it aligns with the first of three main measures highlighted in the STEM initiative of the Malaysia Education Blueprint (2013-2025) to raise student interests through new learning approaches (and enhanced curriculum) (Ministry of Education Malaysia).

6. Acknowledgement

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Appendix

Appendix 1: Experiment manual for apple fruit juice clarification

Title: Apple fruit juice clarification

Introduction

Enzymes

Enzymes are biological molecules (proteins) that responsible for the metabolic processes that sustain life. They are highly selective and catalyses complex reactions occur everywhere in life. Enzymes function is affected by factors such as temperature and pH. The optimum temperature for pectinase to function falls between 45 to 55 °C and work well at a pH of 3.0 to 6.5 (acidic range).

Biotechnology Application

Fruit juices are products for direct consumption and are obtained by the extraction of cellular juice from fruit upon pressing. Nearly all fruits and berries contain pectin and other polysaccharides. Pectin is a structural polysaccharide contained in the cell wall of plant. The presence of soluble pectin in juice causes hazy appearance. The addition of pectinase enzyme in the juice industry increases the yield of juice and helps to maximize the production of CLEAR juice. Production of fruit juice with enzymes is an essential practice in the juice industry today.

Objective

To study the effect of temperature and pH of pectinase enzyme for the production of clear apple juice.

Procedure 1

Effect of temperature

Label 8 test tubes, 4 “50°” for pectinase and 4 “RT” for control.

↓

From the 4 “50°” and “RT” test tubes, label 2 test tubes as “P” and another 2 as “C”, respectively

↓

Cut 1 apple into small pieces.

Weigh 100 g of the apple and put it into a blender.

↓

Add 200 mL of distilled water into the blender.

↓

Blend the apple pieces into juices at speed of 2 for 30sec.

↓

Without removing the lid of the blender, pour out the juice (without the pulp) from the blender into a beaker. The apple juice produced is cloudy in appearance.

↓

Stir the apple juice well to distribute any suspended particles evenly. Add 10 mL of apple juice into each test tube.

↓

Add 1 mL of pectinase into test tubes labelled “50°.P” and “RT.P”.

↓

Add 1 mL of distilled water into “50°.C” and “RT.C”.

↓

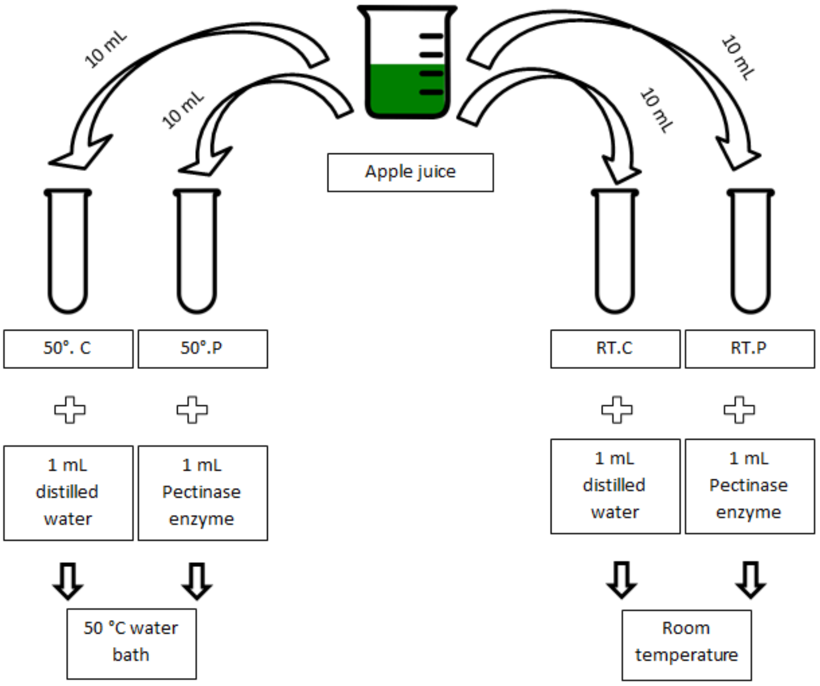
Cover with stopper; mix the contents in the tubes thoroughly.

↓

Put test tubes labelled with “50°.P” and “50°.C” into the 50 °C water bath.

↓

Observe the tubes and record the appearance of their contents at 10 minutes interval over a half hour period.



C=Control

P= Pectinase

Procedure 2

Effect of pH

Label 8 test tubes, 4 "acid" for pectinase and 4 "alkaline" for control.

↓

From the 4 "acid" and "alkaline" test tubes, label 2 test tubes as "P" and another 2 as "C", respectively

↓

Cut 1 apple into small pieces.

↓

Weigh 100 g of the apple and put it into a blender.

↓

Add 200 mL of distilled water into the blender.

↓

Blend the apple pieces into juices at speed of 2 for 30sec.

↓

Without removing the lid of the blender, pour out the juice (without the pulp) from the blender into a beaker. The apple juice produced is cloudy in appearance.

↓

Test the pH of the apple juice with blue litmus paper. The litmus paper should change colour from blue to red, indicating acidic pH.

↓

Stir the apple juice well to distribute any suspended particles evenly. Add 10 mL of apple juice into each test tube.

↓

Add 1 mL of alkaline solution into test tubes labelled "alkaline.P" and "alkaline.C".

↓

Add 1 mL of pectinase into "acid.P" and "alkaline.P", respectively.

↓

Add 1 mL of distilled water into "acid.C" and "alkaline.C".

↓

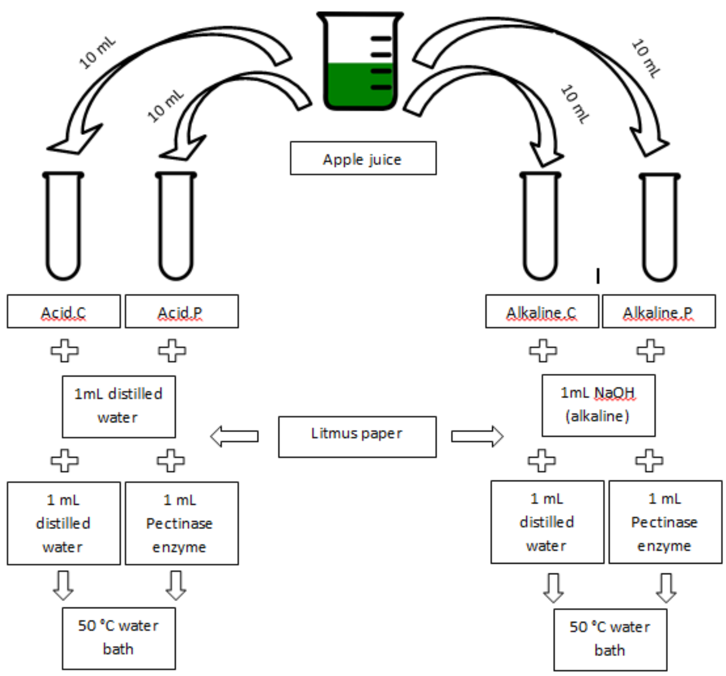
Cover with stopper; mix the contents in the tubes thoroughly.

↓

Put all the test tubes into the water bath set at 50 °C.

↓

Observe the tubes and record the appearance of their contents at 10 minutes interval over a half hour period.



Expected observation

50°.P
Acid.P

50°.C
RT.C
RT.P
Acid.C
Alkaline.C
Alkaline.P

Thank you

Reference: (i) Enzymes in fruit juice production. In a jam and out of juice. www.ncbe.reading.ac.uk/ncbe/protocols/inajam/pdf/jam01.pdf

Appendix 2: Pre-experiment questions

Pre experiment questions: Fruit juice clarification using pectinase

1 What is Biotechnology?

2 Define what are enzymes and explain their general role.

3 Are the roles of enzymes specific?

4 In general, how is an enzyme affected by high temperatures?

5 In general, how is an enzyme affected by changes in pH?

Appendix 3: Post experiment questions

Post experiment questions: Fruit juice clarification using pectinase

1 What is Biotechnology?	
2 Define what are enzymes and explain their general role.	Example of pectinase in this experiment, and you see the apple juice going from cloudy to clear
3 Are the roles of enzymes specific?	In this case, can you replace the pectinase with another type of enzyme and expect to see the same results?
4 In general, how is an enzyme affected by different temperatures?	In this case, warming the pectinase to 50°C and leaving it at RT
5 In general, how is an enzyme affected by changes in pH?	Did the adding alkali to the juice-enzyme mixture change the results?
6 Comments on this experience/experiment:	Egs. Did this Juice workshop help you better understand enzyme activity? Did this Juice workshop help expand your knowledge on the application of enzyme in the industry?

Appendix 4: Marking rubric

Post experiment questions: Fruit juice clarification using pectinase

1 What is Biotechnology?

Biotechnology is the science of using living organisms, or the products of living organisms, for human benefit — to make a product or solve a problem / Biotechnology is the manipulation of living organisms (or parts of organisms) to make products useful to humans.

2 Define what are enzymes and explain their general role.

An enzyme is a protein that function as a biological catalyst; enzyme is the biological catalyst that increases the rate of a chemical reaction and is not changed by the reaction. [In this case, it involves enzyme catalyzed depectinization of suspended pectin particles stemming from the plant cell walls, other disrupted cell wall and cell materials that contribute to juice turbidity]

3 Are the roles of enzymes specific?

Yes, enzymes show specificity in terms of the complementary shape and fit of the active site with the substrate (enzyme-substrate complex), substrate and product

4 In general, how is an enzyme affected by high temperatures?

Increased temperature has an impact on enzyme activity in terms of kinetic energy, shape and fit, frequency of effective collisions and ultimately, denaturation

5 In general, how is an enzyme affected by changes in pH?

Changes in pH such as alkali will impact enzyme activity in terms of shape and fit and denaturation