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Enhanced learning of biotechnology students by an inquiry-based cellulase laboratory

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This study explored the effectiveness of an inquiry-based cellulase laboratory unit in promoting inquiry in undergraduate students in biotechnology. The following tools were used to assess the students' achievements and attitude: conceptual understanding test, concept mapping, students' documents, CLES questionnaire, students' self reflection, and interviews. Judging from their conceptual understanding test results and concept mapping, students gained significantly more content knowledge on enzyme-substrate interaction and its application. In addition, students' reports on their projects revealed that they have developed their critical thinking, scientific process skills and abilities to apply knowledge on enzyme cellulase to industrial application. The students reacted positively to this teaching strategy as demonstrated by results from questionnaire responses, students' self reflection and interviews. The success of this inquiry-based laboratory unit might be due to both the context which was of interest to students, and the instruction method which ranged from a guided to a more open inquiry. Most importantly, the teacher in this study had mastery of both content and pedagogical techniques. This inquiry-based cellulase laboratory unit provided significant benefits for teaching and learning science for biotechnology students. It promoted acquisition of content knowledge and skills such as asking good questions, predicting, problem solving, drawing conclusion, and communication. This inquiry-based laboratory unit may serve as a guideline or framework for implementing a dynamic instruction with a range of inquiry level for the undergraduates.

Keywords: biotechnology, cellulase enzyme, inquiry, laboratory, undergraduate student

Introduction

Recent educational reforms usually expect students to develop their intellect, knowledge, morality, and skills in order to live well in the age of globalization (Australia Capital Territory Parliamentary Counsel, 2004; Office of the National Education Commission [ONEC], 1999; National Research Council [NRC], 2000). Lifelong learning has become one of the policy discourses of many countries to enable students to continuously use what they learn in science and related skills for their daily and professional life (Dehmel, 2006; Wang, Song, & Kang, 2006). It has been widely recommended that the learning approach should be changed from teacher-centered to student-centered one with a balance of knowledge, skills, and attitudes. These educational reforms recommend incorporating inquiry to classroom. It is believed that through inquiry one can construct the interrelated knowledge and understanding (NRC, 2000).

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However, little progress has been made with respect to the inquiry process at the tertiary level. College professors, especially at the undergraduate level, place less importance on knowledge construction and inquiry skills than the school teachers (Australia Capital Territory Parliamentary Counsel, 2004). The obstacles to the incorporation of inquiry laboratories may in part due to the instructors' lack of preparedness for inquiry and others constraints.

Inquiry at the undergraduate level is of importance because the graduates will be encountering the real world and they need to apply their knowledge and understandings to real world situations. Unfortunately most undergraduate instructions, including laboratory experiments, are based on structured inquiry (Buck, Bretz, & Towns, 2008; Roth, McGinn, & Bowen, 1998) despite obvious benefits of more open inquiry instructions. Inquiry teaching and learning methods affect student performances, for example in solving problems, reflecting on their work, drawing conclusions, and generating prediction. These qualities are necessary for a high-achieving graduate.

Thus in this research study, we have developed an inquiry-based laboratory for the undergraduate students to increase their inquiry tendency. The cellulase-cellulose interaction was used as a case study because the context is relevant to everyday life and it is the topic of interest to biotechnology students in this study.

Theoretical Framework

The theoretical framework of this study was drawn from two main areas of the literature: hands-on activity and inquiry-based approach. However, it is important to understand the educational theory underpinning of this study**.**

Constructivism

From the 1990s, constructivism has influenced many education research studies as well as being the doctrine that underpins research programs in science education. At that time, constructivist teaching methods were beginning to be widely advocated and developed (Matthews, 1998). Some educators categorized constructivism into two main areas. For example, Driver, Asoko, Leach, Mortimer, and Scott (1994) and Child (2007) described two major traditions in explaining the process of learning science based on Piaget's and Vygotsky's works: personal or individual and social constructivism. Learners' learning is a process of personal, individual construction arising from their activities (Driver et al., 1994). The learner does not merely record the material to be learned. Rather, the learner constructs his or her own mental representation of the material to be learned, selects information perceived to be relevant, and interprets this information on the basis of their existing knowledge and current needs, adding information not explicitly provided in order to make sense of new material (Shuell, 1993). In social constructivism the communities are social and culture factors that are important for the cognitive constructions of individuals (Driver et al., 1994). Indeed, two major traditions of constructivism are used to frame this research study.

Teaching strategies based on constructivism should focus on providing students with physical experiences that induce cognitive conflict and encourage students to develop new knowledge schemes. Classrooms are places where students are actively engaged with others in an attempt to understand and interpret phenomena for themselves, and where social interaction in groups is seen to provide the stimulus of differing perspectives on which individuals can reflect. The laboratory class is seen as a well-designed resource that allows students to perform the experiments and other activity based learning in science and science education. These activities will challenge learners' prior conceptions and encourage learners to recognize their personal theories. Laboratory activities or practical works with support by group discussion or group learning form the core of such pedagogical practices (Driver et al., 1994; Palmer, 2005).

Laboratory Work

Laboratory work is an active learning activity which is consistent with student-centered strategies based on a constructivist learning-teaching approach (Taraban, Box, Myers, Pollard, & Bowen, 2007). It is considered an important part of teaching and learning science. It involves students performing experiments with concrete objects and concepts. Not only promoting science content, it also promotes science process skills, creative thinking, problem solving ability, and the scientific method (Hofstein & Lunetta, 2004). Similarly Nakhleh, Polles, and Malina (2002) and Wang and Coll (2005) stated that students learn science more effectively by engaging in practical work where they have opportunity to gain knowledge in the same way as scientists do, to do science by themselves. In addition, Berry, Gunstone, Loughran, and Mulhall (2001) claimed that students have learned or verified facts, theories, and principles from performing laboratory activities. As Havdala and Ashkenazi (2007) pointed out, when students engage in laboratory activities, they are expected to link previous theoretical knowledge with experimental design, data analysis, and experimental interpretation and to link laboratory results with theory. According to Wellington (1998), the benefits of the laboratory activities for students in learning science can be summarized in three domains: to develop the cognitive domain (e.g. science content and the nature of science); to develop the affective domain (e.g. promote positive attitude toward science); and to develop skills (e.g. science process skills, laboratory skills, problem solving skills, inquiry skills, and communication skills).

Generally, students perform laboratory activities by following a procedure in the laboratory manual (aka cookbook), and they are unable to meaningfully summarize the important aspects of an experiment they have just completed (Lunetta, 1998). Similarly, Parkinson (2004) reported that practical work consisting of a list of step-by-step instructions conveys the wrong message to students about the nature of science. Therefore, many research studies incorporated laboratory work with other teaching methods such as problem based learning (Das & Sinha, 2000), research based or project based learning (Smiley, 2002), and inquiry based learning (Wallace, Tsoi, Calkin, & Darley, 2003). Nakhleh et al. (2002) suggested that teachers should use inquiry oriented laboratories, allow students to explore open-ended questions, and make the laboratory a link to real world experience and up-to-date knowledge.

Inquiry-Based Approach

Inquiry-based learning refers to the pedagogical strategy that uses the general processes of scientific inquiry as its teaching and learning methodology. This approach emphasizes student questioning, investigating, and problem solving similar to the process scientists use to conduct their inquiries and investigations in the laboratory, at field sites, in the library, and in discussion with colleagues in such activities (Bybee, 2004; DeBore, 2004). The National Science Education Standard (NRC, 2000) identifies five necessary components of inquiry based teaching and learning: student engages in scientifically oriented questions, student gives priority to evidence in responding to questions, student formulates explanations from evidence, student connects explanations to scientific knowledge, and student communicates and justifies explanations. It is important to note that inquiry based learning does not require students to behave exactly as scientists do (DeBore, 2004).

Bell, Smetana, and Binns (2005) illustrated and named each of Herron' ideas (Herron, 1971) of level of inquiry. Level one is confirmation; students confirm a principle through activities in which the results are known. Level two is structured inquiry; students investigate questions using the procedure provided by the teacher. Level three is guided inquiry; students investigate teacher's questions by designing their own procedure. Finally, level four is open inquiry; students investigate questions related to learning topics by selecting questions and designing procedures by themselves. In addition, inquiry based learning approach can be an active learning approach (or dynamic of learning) that ranges from more structured, teacher-guided inquiry to more open ended, student-centered inquiry (Hammerman, 2006).

The concepts of constructivism, both individual and social, laboratory work, and inquiry based approach as mentioned above were used to underpin this study. Because the purpose of this inquiry-based laboratory focused on (1) the students understanding of concepts involved in cellulase activity and applications and in addition, (2) their perception of the environment of the laboratory unit, the research questions are as follows:

(1) Can the inquiry-based cellulase laboratory unit assist the students in understanding concepts about cellulase activity and its applications?

(2) What are the student's perceptions of the classroom environment of the laboratory unit?

Methods

Study Design

This research was designed as a case study in order to provide an opportunity to obtain detail views of participant's perceptions, to identify and recognize themes, and to conduct research in authentic contexts as suggested by Merriam (1998) and Punch (2005). The curriculum and lesson plan was designed based on the student-centered approach under the Thai National Education Act of B.E. 2542 (ONEC, 1999) which is similar to those of Australia, (Australia Capital Territory Parliamentary Counsel, 2004), New Zealand (New Zealand Ministry of Education, 2009), and USA (U.S. Department of Education, 2009).

The participants of the study were 54 fourth-year Thai undergraduate students in biotechnology in a most competitive university. They were all enrolled in the industrial biotechnology course in 2008 academic year. They were 14 males and 40 females aged between 20-23 years. These students were randomly organized into 10 groups of five to six students.

An inquiry-based cellulase laboratory unit comprised of three phases was designed as illustrated in Figure 1. and Table 1. Before the exploration phase the students were provided with information on scientific research activities such as objectives, research processes and ethical issues for the participants. Then the students were given the consent form before the experiment.

Inquiry-Based Cellulase Laboratory Unit

Cellulase – cellulose interaction was used as a learning topic in this intervention. The study design provided opportunities for the students to study relevant topics related to the real world situation, i.e., renewable energy, food industry or textile industry. Cellulose can be easily found in daily life materials such as wood, paper and many wastes from agriculture process such as rice straw, sugar cane bagasse, and corncob and thus can be considered as a renewable bioenergy source, it can be converted to alcohol. Cellulose is broken down to glucose by the group of enzyme cellulase. In this laboratory unit, coconut gel (bacterial cellulose) was selected as the

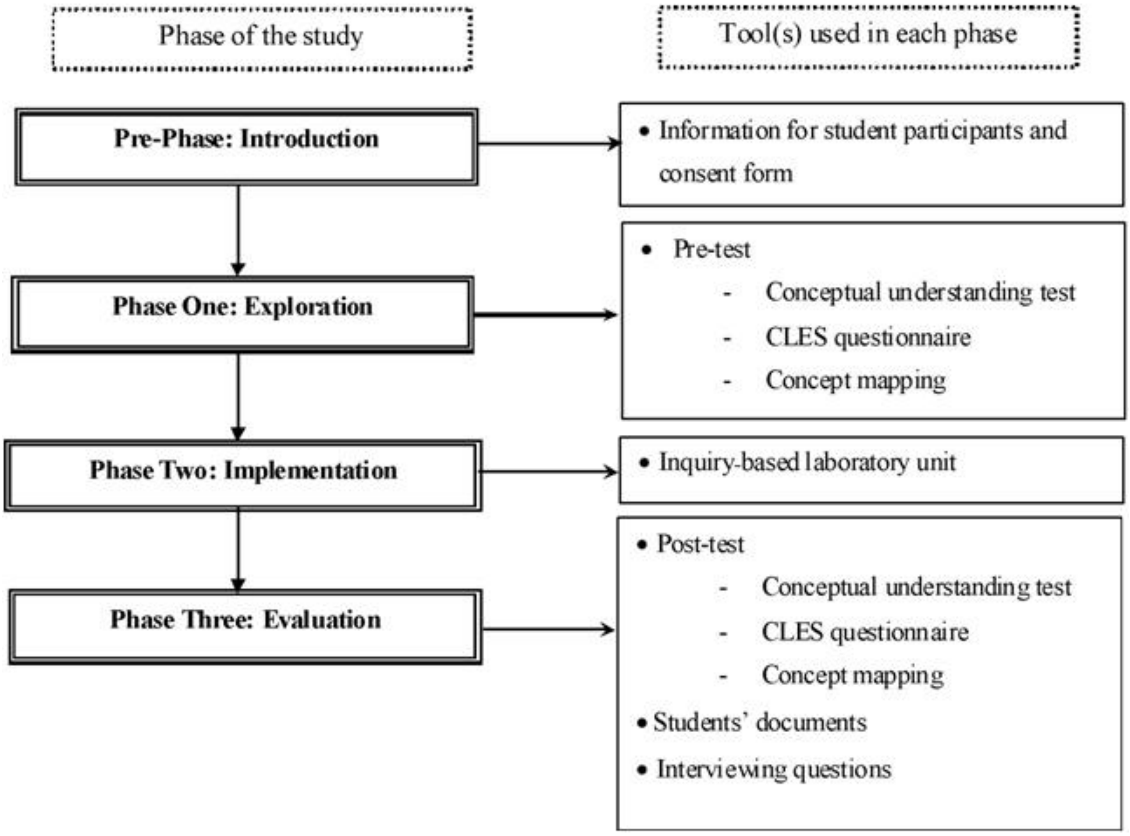

Figure 1. Framework of the study design

substrate for this activity because it is more amenable to enzymatic digestion than the conventional substrates, for example, Avicel, filter paper, CM-cellulose (Ghose, 1987).

The summary of the inquiry based cellulase laboratory unit is shown in Table 1. The learning unit comprised three of a 3-hour sessions over a period of three weeks, plus extra time for students to create and conduct their own project. This study design ranged from a guided inquiry in the beginning to an open inquiry in the second investigation (Table 1). This unit encourages students to plan and conduct their own experiment, to share their ideas with peers, and to apply their knowledge to new situation(s) or solve new problems. Teacher and teacher assistants acted as facilitators during the laboratory class. The teacher had mastery of both content and pedagogical knowledge, and the teacher assistants have already been trained for this task.

Data Collection and Analysis

Five tools were used to collect data from the students during the three phases: conceptual understanding test, concept mapping, laboratory group report, CLES questionnaire, and student interviews.

Table 1. Summary of the inquiry-based learning unit on cellulase

Description	Activities
1st investigation: Guided inquiry approach (three hrs)	Each group of students conducts the experiment under teacher's facilitation to measure the cellulase activity by using two methods: following the decrease of the substrate and the increase of the products. Then the students share their results with peers and discuss with class.
2nd investigation: Open inquiry approach (three hrs)	Each group of students plan and conduct their own experiments to investigate factors affecting cellulase activity. They select their own method(s) to measure cellulase activity.
Extra time (for student's projects)	Each group of students applies their knowledge on cellulase-cellulose interaction to new situations. They create their own projects on application of cellulose for industrial use. For example, converting a variety of cellulose wastes to alcohol as renewable energy, and using cellulase in textile processing and in animal feed supplies.
Presentation and discussion	Each group of students analyzes and transforms data from the 2nd investigation and from their projects. They present their results to their class with extensive discussion among peers. Students and teacher discuss and conclude the whole concepts of the learning unit. Students' reflection

Eight open-ended questions of understanding test were administered to students before and after the teaching-learning process. The test was developed based on objectives of laboratory in industrial biotechnology course. The questions were verified by three experts for content reliability and validity. This tool was used to answer the first research question on whether an inquiry-based cellulase laboratory unit can assist the students in understanding enzyme concepts.

The 42 items in six scales (i.e. seven items in each scale) of CLES questionnaire were adapted from the Constructivist Learning Environment Survey (CLES) (Salish I Research Project, 1997). The six scales are Personal Relevance, Scientific Uncertainty, Critical Voice, Shared Control and Student Negotiation. Each item consisted of five responses (Likert scale): almost always, often, sometimes, seldom, and almost never. The Cronbach's alpha was used to provide the coefficient of the reliability of the instrument by using statistics software package, SPSS version 12. The Cronbach's alpha reliabilities of all scales of pre-and post-questionnaire were 0.88 and 0.99. The internal reliabilities of each scale of the pre-questionnaire ranged from 0.68 to 0.96. This tool was used to investigate students' perceptions of the constructivist classroom environment. This method was used for collecting data to answer the second research question on student's perceptions of an inquiry-based cellulase laboratory unit.

The pre- and post-scores from CLES questionnaire and understanding tests were analyzed by t-test in order to evaluate the statistic significance between two sets of data.Each student was asked to construct his or her own concept map at the beginning and the end of the teaching and learning process. The concept maps were evaluated by using scoring rubric adapted from Moni, Beswick, and Moni (2004). Each group of students was asked to submit laboratory reports as well as project reports. These data were evaluated by using scoring rubric adapted from Doran Boormand, Chan, and Hejaily (1993).

The students' concept maps and reports were used to support data on students' understanding of the concept on cellulase activity: the first research question. Semi-structured interviews were conducted with 7 randomly selected students to obtain more in-depth information mostly on attitude. Each 40 minute interview was recorded, transcribed and analyzed by using the thematic approach. These data were used to support students' perceptions of the constructivist classroom environment: the second research question.

Results

The results from understanding tests in Table 2 concerning three main enzyme topics revealed that all the post–test scores were significantly higher than those of the pre-test. Higher gains were observed on the application aspects and methods for measuring enzyme activity when compared to the basic knowledge on cellulase – cellulose interaction. The results suggested that students could figure out how to measure cellulase activity and apply the knowledge gained after the inquiry-based laboratory activities.

In terms of students' documents, laboratory reports from each group were analyzed by using the scoring rubric developed from Doran et al. (1993). This rubric consisted of four main criteria: 1) introduction/ objective/ hypothesis; 2) procedure for investigation; 3) data & results; and 4) discussion & conclusion. The overall scores were 20 points, a maximum of five points for each criterion. Four levels of quality were assigned: 0 to 1.25 for beginning, 1.26 to 2.5 for developing, 2.56 to 3.75 for accomplished, and 3.76 to 5 for exemplary. The beginning level refers to the incomplete details of each criterion in the report. Most details were missing such as inappropriate statement of hypothesis, absence of objective of the experiments, inappropriate procedure, and incomplete results and conclusion. In the exemplary level, the reports contain all essential details such as appropriate statements of hypothesis, procedure, and conclusion drawn from results. Table 3 shows the mean scores of two laboratory reports. The first report was drawn from the first investigation on measuring enzyme activity. The second report was from students' own investigation in the subsequent experiment. The quality of the first laboratory reports was

Table 2 Students' scores on tests administered before and after completing the learning unit

Topic	Mean scores of conceptual understanding test		Standard deviation		*t*
	Before intervention	After intervention	Before intervention	After intervention	
Basic knowledge of cellulase-cellulose interaction	3.44	3.88	0.67	0.72	4.610*
Cellulase measurement method	1.84	4.46	1.22	0.71	14.168*
Application of cellulase	3.26	6.06	1.16	1.35	13.590*
Overall	7.91	14.31	3.20	2.27	15.344*

* Significant difference (p< 0.001)

Table 3 Evaluation of students' laboratory group reports (Doran et al., 1993)

Criteria	Scores of Report 1 (Means±SD)	Quality	Scores of Report 2 (Means±SD)	Quality
1. Introduction/ Objective/ Hypothesis	2.00 ± 0.87	Beginning	3.50 ± 0.71	Accomplished
2. Procedure for Investigation	3.10 ± 0.32	Developing	3.80 ± 0.63	Accomplished
3. Data & results	3.40 ± 0.52	Accomplished	4.00 ± 0.47	Exemplary
4. Discussion & conclusion	3.70 ± 0.48	Accomplished	4.80 ± 0.42	Exemplary
5. Total	12.10 ± 1.70	Accomplished	16.10 ± 1.37	Exemplary

placed in the beginning and developing stages by criterion number 1 and 2 and accomplished by criterion number 3, 4, and 5. However, the quality of the second reports on students' own investigations improved: becoming accomplished by 2 criteria and exemplary by 3 criteria. The results illustrated student improvement from the guided-inquiry in the first phase to open inquiry after the subsequent phases.

Results of students' concept map evaluation, before and after the learning process, are shown in Table 4. Three main criteria as adapted from Moni et al. (2004) were used to evaluate students' concept maps. Each criterion has a maximum score of 4. The first criterion refers to content of the concept map: the maximum score means that all relevant enzyme concepts are correct with links when compared with the reference map constructed by experts and the most complex ones by the students. The maximum score of second criterion on logic and understanding means that the concepts of enzyme and links are clearly demonstrated. The maximum score for the third criterion on presentation refers to the concept map that is neat, clear, and legible, and has easy-to-follow links and no spelling errors. The results showed that the mean scores of the students' concept maps significantly improved after the learning process according to the three criteria on content, logic and understanding, and presentation of the concept maps. The concept map after completing the learning unit clearly showed more complexity with more concepts and links. The results thus suggested that this inquiry learning strategy helped student to construct and conceptualize the knowledge on enzyme cellulase from basic principles to applications.

The students' perception of the learning unit was measure by a CLES questionnaire. The students' responses to pre and post questionnaires are shown in Figure 2. In the pre-CLES questionnaire, the students were asked to think about previous classroom experiences in the traditional learning methods whereas the post-CLES questionnaire allowed students to think about the inquiry learning unit they had just completed. The overall post-test scores were significantly higher than those of the pre-test as determined by a paired t-test. However, upon looking more closely into each scale, the significant difference was observed in personal relevance, scientific uncertainty, critical voice, student negotiation, and attitude, but not in shared control. These results show that the inquiry learning unit is more constructive than that in the traditional laboratory. The students perceived that the experiences from the learning unit were more relevant to their everyday interests and activities than the traditional classes. They also appreciated the development of scientific knowledge which was shaped by social and cultural

Table 4 Evaluation of students' concept maps using scoring rubric adapted from Moni et al., (2004)

Criteria	Scores (Means±SD)	
	Pre-map	Post-map
1. Content: all relevant concepts of enzyme are correct with links (Max. 4).	1.67 ± 0.74	3.30 ± 0.50
2. Logic and understanding: understanding of facts and concepts of enzyme is clearly demonstrated by correct links (Max. 4).	1.51 ± 0.70	2.70 ± 0.70
3. Presentation: concept map is neat, clear, and legible, has easy-to-follow links and has no spelling errors (Max. 4).	1.51 ± 0.61	3.00 ± 0.50
4. Total (Max.12).	4.40 ± 2.00	8.30 ± 2.90

influences, and by human interests and values. The learning unit provided opportunities for students to question and share control of the teaching and learning methods and classroom activities by providing them with the opportunity to design and manage their own learning activities. In addition, students perceived that they have more opportunity to negotiate with peers and teacher than the traditional classes. Moreover, more percentage difference between pre and post-test was observed in attitude, suggesting that the students had a strong positive attitude toward the inquiry laboratory.

The students' points of view on the inquiry-based cellulase laboratory unit were also gathered from interviews to support the CLES questionnaire data. The results showed that the students were more active in the given learning activities than the traditional classes. They had more opportunities to conduct their own experiments and projects, to communicate their ideas and data with peers, and to draw conclusions from evidence. Additionally, the students responded that the topics/activities of the learning unit were more relevant to their everyday life.

The following is an excerpt from interviews about the students' opinions on the learning unit compared with traditional classroom activities:

> *"Totally different. In the previous traditional lab, we went strictly through the given protocol without thinking. In the present lab, each group set its own conditions resulting in different data in which we could share and draw our own conclusions. It was very challenging."*
>
> *"We realized that our roles as students in the inquiry-based lab have changed accordingly, we were proud that we could think by ourselves, not having to wait for answers like before"*

Questioned on their most favourite activity, the students liked all activities as shown in the following excerpt.

> *"The whole activity, because it resembles real life events and the results could be easily seen."*

One student in a group said that they like to conduct their own experiment or project thus

> *"We liked to design and create our own project, since we had freedom in thinking and we could prove our own proposal."*

Some students appreciated this learning strategy because they could learn by communicating with peers:

> *"We love this collaborative activity because we could learn through discussion with peers."*

When students were asked to think about what they had learned or gained from the learning unit apart from the enzyme concepts, some students replied:

> *"I learned to think before asking questions or giving answers, although it was very difficult"*
> *"I realized that scientists have to think and do a lot before coming up with a good piece of work"*

However, some of students did not seem to understand their role in the new ap-

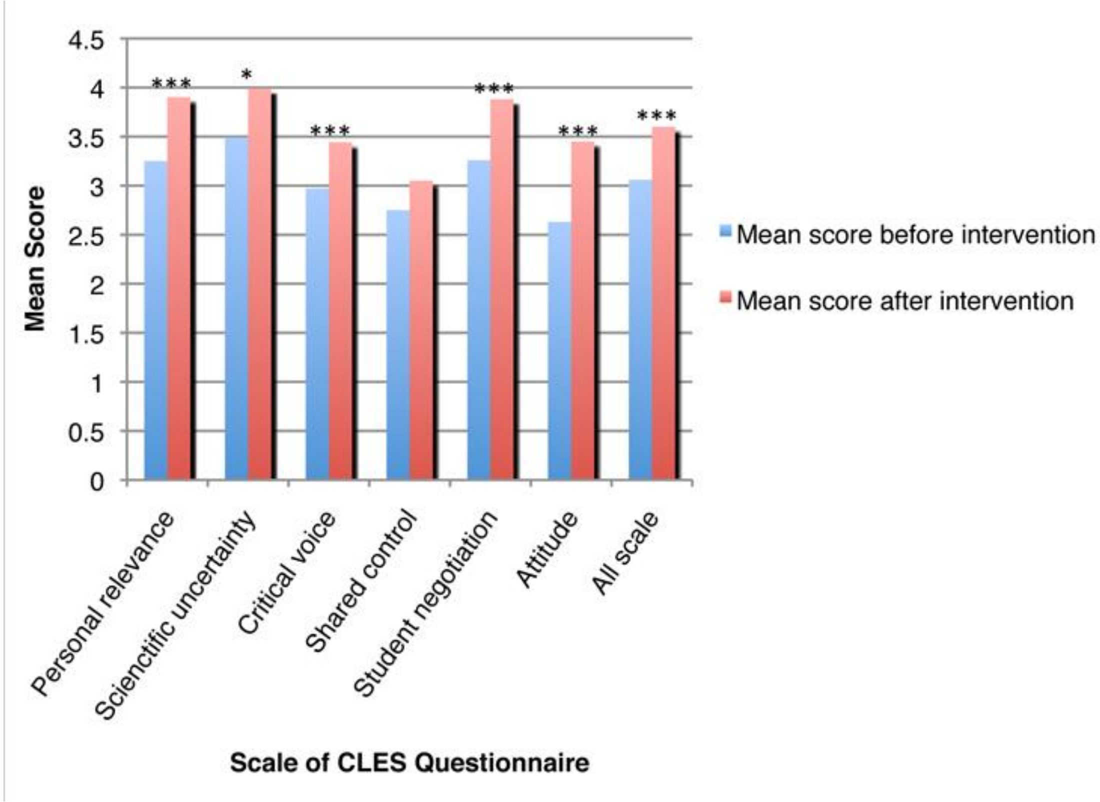

Figure 2. Students' perception of learning environment before and after implementing the inquiry based laboratory unit as measured by CLES questionnaires

proach.

> *"It was confusing at first, but even though we could adjust ourselves later, still we did not rise to the level the teacher expected."*
>
> *"Teacher should give a clearcut direction at least in the first laboratory, otherwise it would be very difficult for us to carry out the subsequent experiments."*
>
> *"We might not get a good results because teacher did not tell us what they should be like."*
>
> *"I still cannot get used to this new way of learning. I am confused about objectives of this laboratory."*

Time is the common limitation of the inquiry based approach. Some students stated that they did like to learn by this approach, however, time constraint is one of the factors that they found stressful.

> *"It was good, but it was time consuming and I had too much work to do compared to the previous lab. This activity was stressful to me."*
> *"Time constraints, need more class time"*

Discussion

That our undergraduates have benefited a great deal from the inquiry-based cellulase laboratory is reflected by their better abilities in knowledge construction, reasoning, communicating and explanation and increased motivation. The students can thus acquire the inquiry attitude from this learning strategy. In addition, they became better at solving problems and applying knowledge to novel situations. These claims are supported by the increased scores in conceptual understanding tests, in concept mapping, and laboratory reports together with those from students' interviews. These findings corroborated many research studies, e.g., of Lord and Orkwiszewski (2006) who implemented the inquiry laboratory approach to college students in introductory biology course. They concluded that inquiry laboratory approach seemed to help students to develop their own understanding of the content, to apply their knowledge to the new situation. They also acquired personal interest in science around them as well as to foster their enthusiasm of the science area. Similarly, Lunsford (2003) found that the biology inquiry-based laboratory help students to construct their own investigations with minimal guides. They reacted positively on the inquiry experiences, practiced working as a team, and incorporated what they have learned into the laboratory report.

The key success factors in this study are in both the context and methodology. The topic used in this study, cellulase enzyme, is of interest to biotechnology students, who want to learn more about its industrial applications. Thus the students perceive inquiry to be beneficial for them resulting in their motivation to learn as suggested by Brown, Abell, Demir, and Schmidt (2006). Additionally, the inquiry approach used in this study was not solely the guided inquiry or open inquiry as frequently used at the lower level or higher level studies respectively, but it was a mixture of the two types. Even though the participants were senior college students, they had little experiences in student-centered learning in a real sense. They had been taught only by the traditional instructions in which they were told the answers and expected to learn mainly from the lecturer. The student-centered activities usually involved reading assignments and presentations to class with little or no discussion with both their peers and teachers (Lunsford, 2003). Since the inquiry laboratory was our students' first experience, they found it not easy to benefit from this learning environment. Although the topic on enzyme cellulase seemed relevant to them, they had learned only the basics about enzyme-substrate interaction and standardized measurements of enzyme activity. Thus a guided inquiry is necessary to provide students with various methods to follow cellulase activity, an important feature needed for the subsequent phase of the open inquiry. In addition, the method of measuring the rate of cellulase reaction in this study was also novel to them both in terms of substrate and enzyme. This may partially explain why the students had a greater improvement in the post test score as presented in the Table 2. This is similar to the findings of Boyce and Walsh (2005) who developed four mini-practicals on phytase activity to investigate the effect of temperature and pH. The students worked in groups to develop a research project to test phytase for inclusion in animal feed. They claimed that this learning unit was particularly suited for biotechnology students undertaking basic biochemistry courses.

Although the effectiveness and constraints of the inquiry based instruction have been extensively reported by several educators, these are mostly at the K-12 levels. For example, Zion et al. (2004) investigated the use of the Biomind curriculum for Grades 11 and 12 where students act as self-directed learners with continuous thinking throughout the inquiry process. Taraban et al. (2007) have used a hands-on inquiry laboratory with high school students to allow them to learn science concepts by conducting experiments and formulating conclusions based on their results. All these results together with many others revealed that the inquiry approach had more advantage than traditional strategy in content knowledge, process skills, and attitudes toward science (Das & Sinha, 2000; DeBore, 2004).

Not so many inquiry based laboratories have been implemented at the college level, as reported by Buck et al. (2008) on the evolution of levels of inquiry (levels 0,1/2,1,2,3) in laboratory texts across science disciplines. The recent laboratory manuals with advances in science have not been accompanied by a corresponding shift to pedagogy into inquiry instruction. The majority of the experiments are of confirmation laboratory type (levels 0) and structured inquiry type (level ½) only 26 and 5 out of 386 items were found to be guided (level 1) and open inquiry (level 2) experiments. Examples of inquiry laboratory for undergraduate students have been conducted in botany by Lord, Shelly, and Zimmerman (2007), in biology by Lord and Orkwiszewski (2006), in chemistry by Khan (2007) and in physics by Bryant (2006). For example, Basaga, Geban, and Tekkaya (1994) developed a 12 weeks learning unit that allow students to engage in providing problems related to the scientific topics such as factors affecting the rate of reactions and isolation of DNA from microorganisms. The laboratory manual provided only the apparatuses used in the experiment they needed to design, to collect and analyze data to find the solutions. Similar to other inquiry approaches our students were asked to design experiments, formulate hypotheses, perform experiments by themselves as guided by instructors, and finally draw conclusions. Students' achievements in knowledge gain and science process skills were found to be higher in the inquiry laboratory when compared to those of the traditional cookbook style. This finding is corroborated by those of Minderhout and Loertscher (2007) who developed a process oriented guided inquiry learning to promote content knowledge, and students' skills.

Again, the design in this research study which started from a guided to a more open inquiry is similar to those of Howard and Miskowski (2005), who developed multi-week inquiry-based cell biology laboratory modules for undergraduate students. The students were involved in experimental design, data collection and analysis, and made connections to real life situation, resulting in improved content knowledge, enjoying laboratory activities and having increased interest in the subject content as well as having developed critical thinking skills. The experimental design in this study is similar to those of Brown et al. (2006) that differ only in degree of guidance and degree of inquiry in the instruction depending on the instructional purposes and procedures, as well as students' background and knowledge.

Results from this study showed that not only enhancing students' knowledge as reflected in tests for understanding (see Table 2), great improvements have been shown in scores of the reports (see Table 3) which increased from the first investigation (guided inquiry on how to measure enzyme activity) to the second investigation (open inquiry on enzyme application). The results indicated student improvements in scientific skills, including hypothesizing, data handling and analysis. The students reflected more on their work, drew conclusion and even generated predictions. As a result, the highest score (exemplary) was in the parts on discussion and conclusion, suggesting students' higher achievement in critical thinking, reasoning and explanation. In addition, the students were more likely to discuss during class presentation. This finding corroborates those of Brown et al. (2006) and Howard and Miskowski (2005) that the inquiry approach seemed to enhance students understanding on the topic and to develop their critical thinking and problem solving skills.

Even though we anticipated that the results from group work would come out better due to idea sharing as reported by Boxtel, Linden, Roelofs, and Erkens (2002). In this study each student was asked to write his or her own concept map without consulting peers in order to investigate each student understanding of the topic. The minimum and maximum scores of 6 and 12 (from total of 12), were obtained indicating that some students were still left behind in spite of the collaborative and participatory activities in this learning unit. The lowest score was in logic (see Table 4). This suggested that although the students could formulate explanation from laboratory evidences, some of them failed to connect explanation to scientific knowledge.

Grant and Vatnick (1998) reported that it is hard for students to conduct open-ended laboratory activities because they lacked sufficient skills to complete them in the limited time available. This happened to be the case in this study (see excerpts from interviews). Thus students should be given more time to develop skills and conduct their experiment. In terms of satisfaction most of the students did enjoy the class. However, in general some teachers as well as students resisted constructivist pedagogy e.g. inquiry-based teaching and learning approach, because they are more comfortable with their present instructional approach. There are teacher constraints such as lack of pedagogical skills as well as weak understanding of the nature of science. In addition, teachers are provided with only general guidelines for the guided inquiry, and they are ill-equipped with guided scientific inquiry teaching in the particular context where there are expected to respond to questions (Furtak, 2006). The teacher and teacher assistants should be supplemented with the professional development programs to provide knowledge and specific and explicit experiences about inquiry-based teaching (Bell, 1998; Wee, Shepardson, Fast, & Harbor, 2007; Supovitz & Turner, 2000). The teachers involved in this study, however, are well-equipped will both methodology and context, and this may explain the success of the present inquiry strategy. To begin with, the students however did not have intentions of learning for the sake of gaining knowledge, but they were induced little by little by class activities.

To the question of what aspects of the inquiry-based cellulase unit did facilitate the students learning, the results on CLES questionnaire (Figure 2) might give a clue to this answer. The students answered a pre CLES questionnaire based on their experiences with their pervious traditional laboratory and post questionnaire after this learning activity. The higher scores of the post questionnaire suggested that the students perceived the inquiry learning environment as providing chances to share control, negotiate and have critical voice which aroused their enthusiasm and critical thinking. Students perceived that the experiences in the intervention to be more relevant to their everyday interests and activities as intended by the study design. The intervention provided more opportunities for students to question the teacher's pedagogical plans and methods, to express concerns about impediments to their learning as well as the opportunities to negotiate with peers and the teacher. Students also acknowledged that science knowledge is evolving and provisional and is shaped by social and cultural influences and arises from human interests and values. In terms of *student negotiation*, the intervention provided more opportunities for students to negotiate with other students and the teacher than the traditional classes. It thus seems the students felt they were engaged in the learning activities where they could reflect on, explain and justify their own ideas to other students. Finally, students seemed to enjoy and engaged in the learning activities in the inquiry based laboratory more than the traditional one.

The great difference between the pre and post CLES questionnaire were in students' attitude (Figure 2) which favored the inquiry laboratory much more than that of the traditional laboratory. This is similar to other findings that the inquiry based activity can engage student and stimulate their interest and increase their enthusiasm (Taraban et al., 2007; Zion et al., 2004). The students' points of view as gathered from interview results also supported this conclusion. All students perceived that the learning environment had changed totally, and this was both challenging and stressing to them. Some of the students admitted that they instinctively prefer to be spoon–fed. However, the inquiry activity was designed in such a way to encourage them to think by themselves. Nevertheless, most of them agreed that collaborative activity promoted their learning and understanding.

In this study, although the majority of the class has seen the benefits of the inquiry class that made them learned from questions and evidences, some students still preferred the teacher-centered way. We may have to pay more attention to their learning style and inspire them at the right moment. Most students liked the freedom to design their own investigations, however, they complained about the workload and insufficient time. The experimental results from their projects supported their complaints that things could be a better if more time was allocated. This seems to be a weak point of this study and should be corrected in future works. The student interviews suggested that most of the students seemed to be ready for the inquiry based laboratory approach, provided that it be connected with the real-life context, conducted by an experienced teacher and given sufficient time.

Conclusion and Implication

This study reports a case study of using an inquiry-based laboratory to enable undergraduate students to construct their own conceptual understanding of enzyme, cellulase in this case. Additionally the students were capable of applying their knowledge to relevant situations, as supported by their abilities to formulate and test the hypotheses in different circumstances.

In an open inquiry environment, the students feel ownership of their projects and most of them recognize the benefits of this learning style. This inquiry based laboratory unit meets the needs of both students and faculty, and thus will become a permanent instruction unit in the curriculum. It is expected to promote student skills and critical thinking needed for pursuit in the graduate program, or in future work generally as quality citizen as well as teachers and researchers. Since it has been a considerable concern at present that college laboratory experiments should change their emphasis from confirming the issues covered in the lecture/text to formulating explanation from evidences. This study should inspire college science teacher to adapt and adopt our findings. Or they can design their learning unit that contains essential feature of inquiry at varying degree of openness. This approach will help to empower the student to be an active learner resulting in higher quality learning as suggested by Kasl & Yorks (2002). Nevertheless, the teacher should have mastery of both content and pedagogical techniques for effective implementation of the intervention program. The science teacher can be trained through a professional development program.

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Biyoteknoloji öğrencilerinin sorgulayıcı temelli selülaz laboratuarı ile geliştirilmiş öğrenmeleri

Bu çalışmada, sorgulayıcı temelli bir selülaz laboratuar ünitesinin lisans düzeyindeki öğrencilerin biyoteknolojideki sorgulamalarının destekleme hususunda etkililiği ortaya çıkarılmıştır. Öğrencilerin başarılarını ve tutumlarını ölçmek amacıyla şu araçlar kullanılmıştır: kavramsal anlama testi, kavram haritası, öğrenci dokümanları, CLES anketi, öğrencilerin kişisel düşünceleri ve mülakatlar. Kavramsal anlama testi ve kavram haritalarından çıkarılan sonuçlara göre öğrencilerin anlamlı biçimde daha fazla enzim-substrat etkileşimiyle ilgili içerik ve uygulama bilgileri kazandıkları tespit edilmiştir. Ayrıca, öğrenciler proje raporlarında eleştirel düşünme ve bilimsel süreç becerilerini geliştirdiklerini, enzim selülaz bilgilerini endüstriyel uygulamalarda kullanma kabiliyetlerinin artığını ifade etmişlerdir. Anket cevaplarında, öğrencilerin kişisel düşüncelerinde ve mülakatlarda çıkan sonuçlar, öğrencilerin bu öğretme stratejisine olumlu tepki verdiğini göstermiştir. Bu sorgulayıcı temelli laboratuar ünitesinin başarısı hem öğrencilerin ilgisinin çeken bir bağlamda verilmesi hem de kılavuzlanmış bir yapıdan açık sorgulamaya kadar değişen bir formattaki öğretim yaklaşımından kaynaklanabilir. En önemlisi, bu çalışmada öğretmenler hem içerik hem de pedagojik tekniklerde bir uzmanlık kazanmışlardır. Bu sorgulayıcı temelli selülaz laboratuar ünitesi biyoteknoloji öğrencileri için bilimi öğrenme ve öğretmede kayda değer faydalar sağlamıştır. İçerik bilgisinin ve iyi soru sorma, tahmin etme, problem çözme, sonuç çıkarma ve iletişim gibi becerilerin kazanılmasını desteklemiştir. Bu sorgulayıcı temelli laboratuar ünitesi, lisans öğrencileri için sorgulayıcı düzeyin değişen açılımlarında dinamik bir öğretimin uygulanması için bir çatı veya rehber olarak sunulabilir.

Anahtar kelimeler: Biyoteknoloji, selüloz enzimi, sorgulama, laboratuar, lisans öğrencisi