As. J. Food Ag-Ind. **2009**, Special Issue, S424-S443

Asian Journal of Food and Agro-Industry

ISSN 1906-3040
Available online at www.ajofai.info

Enhancing Conceptual Understanding and Critical Thinking with Experiential Learning: A Case Study with Biological Control

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Abstract

This study examined how two contrasting classroom experiences (experiential vs. traditional learning) affect the conceptual understanding and critical thinking of biology student. Using biological control of plant disease, we found that compared to students in a traditional learning class, students in an experiential learning class better understood organismal interactions in biological control systems and were more critical of how biological control organisms affect the environment. For both classes, we analysed the students' abilities to give coherent and thoughtful answers to open-ended questions, to demonstrate understanding of the material in interviews, and to construct a complex concept map. The experiential learning students also applied their knowledge in designing science projects, which demonstrated impressive understanding of the underlying biology and its relationship to society and environment. The experiential learning students appreciated the hands-on activity and believed that the experience increase their understanding of both biological processes and the environment. Our study shows that experiential learning can enhance both scientific thinking and creativity and thus should be used to improve biology courses.

Keywords: Biological control; Critical thinking; Experiential learning

Introduction

In science education, hands-on activities facilitate learning by helping to draw students and teachers into the real world of science. Unfortunately, there is still a paucity of effectively designed classroom experiments that expose students to the real world while enhancing their cognitive learning (Fenwick, 2001). Deficiencies in experimental activities in the classroom may explain student failure to understand scientific concepts (Baumert et al., 1997). Although a balance of theory and practice seems to increase scientific understanding in the classroom, science teaching currently seems to favor theory and tends to neglect practical experience (Euler, 2001). As a result of the virtual absence of hands-on activity in school, the preparedness of science students is decreasing relative to occupational demands (Asian Development Bank, 2003). A variety of national stakeholders, including business and educational leaders, politicians, parents, and public agencies, have called for a long-term transformation of the educational system to produce graduates who can intelligently engage in global issues that require local action and who are better able to solve problems and think critically. Specifically, business leaders are calling for graduates with advanced analysis and communication skills, for instructional methods that improve lifelong learning, and ultimately for an educational system that builds a nation of innovative and effective thinkers (Business-Higher Education Forum and American Council on Education, 2003). Education leaders are similarly calling for institutions to produce graduates who can think critically and communicate effectively, and who employ lifelong learning skills to help solve important scientific and civic problems (Association of American Colleges and Universities [AACU], 2005).

Many educational institutions consider critical thinking to be one of the most important indicators of student learning quality (AACU, 2005; Department of Curriculum and Instruction Development, 2001). Teaching to support the development of critical thinking skills has become a major educational objective since the ministries of education in many countries have tried to reform education. Educational organisations have tried to shift from traditional teacher-focused instruction to a more student-centered learning that encourages discovery, reflection, and improved critical thinking (Quitadamo and Kurtz, 2007). In Thailand, the Institute for the Promotion of Teaching Science and Technology (IPST) has supported this trend with recommendations to improve the advanced thinking skills that support scientific literacy (IPST, 2001). Critical thinking is very close to scientific thinking: when a student uses the scientific method to study or investigate nature or the universe, he or she learns to be critical, i.e., to seek out and understand the limitations and strengths of data and inferences. When one uses the methods and principles of scientific thinking to solve economical or philosophical problems or to simply answer personal questions about oneself or the meaning of existence, one is practising critical thinking. By thinking critically, considering the strengths and weaknesses of different perspectives on solutions to the problems, one increases the chances of finding the best solution. (Schafersman, 1997).

Much research has shown that people construct knowledge from their experiences (Baker et al., 2002; Kayes, 2002). The process of experiential learning is especially important for children, who need sensory and physical activities to learn and develop. Experiential education, however, is not a new movement in the field of education, and numerous scholars have proposed learning models with the characteristics of experiential learning (Wulff-Risner and Stewart, 1997). John Dewey, one of the most influential educational theorists of the twentieth century, emphasised the importance of experiential learning in 1938, and since then numerous models of experiential learning have been proposed. Kolb and Fry (1975) constructed a four-mode model whereby knowledge is gained through experience. In this famous model, an experiential learning circle is composed of concrete experience, observation and reflection, formation of abstract concepts, and testing in new situations. The concrete experience results in the creation of concepts that integrate the learner's observations into logically sound theories.

The learners use these theories to make decisions and solve problems in the new situation; they would then get more experiences by doing hands-on activities to test their concepts.

The goals of experiential learning are both cognitive and motivational: experiences in the field or laboratory will suggest questions to students that will lead to active learning. Student reporting of their experiences leads to class discussion. More importantly, actual experience connects learning and thinking, and demonstrates to students the value of combining both activities. Laboratory experiences will not only motivate students to learn current course materials but also increase their intrinsic interest in further learning. Empirical research by Brandell and Hinck (1997) has provided evidence that experiential learning increases student ability to apply course concepts to new situations and also increases social responsibility and personal efficacy. In addition, Howe and Warren (1989) suggested that experiences in environmental education will effectively develop critical thinking skills by challenging students with topics and problems that cut across the school curriculum and enhance integration of the knowledge. Environmental topics provide real problems that can be studied or simulated and that can be adjusted to student level. Additionally, finding workable solutions to environmental problems requires choices and decisions based on a critical examination of information and opinions.

In general, the secondary biology curriculum aims to develop student understanding of the concept of organismal interrelationships in nature (National Academy of Science, 1995; IPST, 2001). More recent reports have described the need for improved biological literacy as well as international competitiveness (Klymkowsky, 2006). It is necessary to promote the research-supported teaching and learning practises, which can help students to develop the cognitive science that is a goal of science learning (Bybee and Fuchs, 2006). Nevertheless, educational research has documented that at the end of the 20th century experiments in the senior biology classroom largely follow recipes or lack practical relevance (Haigh, 2007). Thus, there is a need for a more balanced approach to science education with an emphasis on both scientific process and content. To enable this dual emphasis, students should be engaged in complex investigations because procedural and content understandings are both essential components of such practical investigations. In addition, scientific investigation encourages the use of both tacit and acknowledged prior knowledge (Haigh, 1999). While investigating, students are encouraged to engage their minds as well as their hands. Though many students find it difficult to transfer what they have learned from practical work in the classroom to open-ended projects, investigative practical work enables students to better understand the nature of the scientific pursuit and the social collective nature of the scientific endeavor (Lewis, 2002). Nevertheless, there is still a lack of effective hands-on activities that can provide direct experience for students. Particularly lacking are activities that enable students to study the relationships of organisms in their natural habitat, a topic in which traditional teaching often failed to increase conceptual understanding and a topic that students often cannot relate to their everyday life and to their society.

At present, the issue of biological control is of increasing importance and is inspiring research in many fields of biology (Pal and Gardener, 2006). Biological control involves the interrelationships between many environmental variables and multiple interactions among organisms and the environment. Because this interrelatedness leads to a good connection between school biology knowledge and real world phenomena, biological control is taught at nearly all levels, from primary school (4th grade) to the university (Jeffords and Hodgins, 1995; Nonnecke et al., 2001). A variety of class activities related to biological control, including laboratory and field investigations, has been designed (Center for Insect Science Education Outreach, 2001). However, the activities usually focus on higher organisms (i.e., beetles, worms, or bugs) that can be easily observed. Microorganisms, while not so easily observed, have important roles in food webs and natural balance and can be important biological control agents. To the best of our knowledge, the education literature contains no reports of how microorganisms in biological control can be used in senior secondary school biology courses, in spite of the need for the students to know the roles and activities of microorganisms in the ecosystem. Therefore, this study was aimed at designing a practical learning activity about the role of microorganisms in biological control. The activity should incorporate experiential learning to enhance conceptual understanding and critical thinking skills of the senior secondary students. The activity should also increase student awareness of social responsibility and environmental preservation.

Research questions

The research questions that guide this work are as follows:

1. How do the designed experiential learning activities help students to construct concepts of biological control?
2. What are the achievements of students after the experiential learning?
3. How does this experiential learning encourage students to think critically?
4. What are the attitudes of students towards the experiential learning on biological control?

Methodology

Research design

Both qualitative and quantitative investigations were used in this study. A "quasi-experiment" was developed to compare two groups of senior secondary students (11th grade) in a school promoting science learning in Thailand. Both groups participated in a 3-week study of biological control (the study was offered as an elective biology course), and all of the 64 students who participated had the necessary background in cell structure and function, diversity of organisms, and nutrition. At the start, the 64 students were randomly divided into two groups: the experiential learning group and the traditional teaching group. Students in the experiential learning group (16 males and 19 females), who were taught according to the teaching sequence described in Table 1, conducted a hands-on biological control experiment and designed their own projects. The traditional teaching group (14 males and 17 females) attended lectures and did not conduct a hands-on experiment or design science projects. The experiential learning group was divided into eight subgroups, with four students per subgroup. The traditional learning group did not have subgroups. At the end, the conceptual understanding of both groups was assessed by the multiple choice questions, analysis of constructed concept map, and conceptual interviewing. Student critical thinking skills related to biological control were evaluated by using critical thinking questions.

Table 1. Teaching sequences for the experiential learning group

Phase/Day	Activities	Time (min)
1	1) Pretest: students take pretest examination (multiple choice questions).	20
	2) Engagement: students are asked the following question: “Can individual organism live alone in the habitat?” And “Why did you answer that way?” The purpose of questioning is to engage students and tie them to the lesson.	10
	3) Briefing contents: teacher briefs the contents of organismal interrelationships in the ecosystems and biological control.	20
	4) Demonstration: teacher demonstrates (hands-on) biological control of anthracnose disease in chili fruit by yeast and basic microbiological techniques (aseptic techniques, media preparation, yeast and mold isolation from the surface of crops, yeast and mold culturing, and slide preparation for microscope observation).	25
	5) Experimental design: students work in groups of four and design the experiments to test their predictions. Their experimental design must include a hypothesis, control group, variables, and methodology. The teacher will approve each plan before implementation.	25
2	6) Students conduct the experiments that they designed. Teacher will act as facilitator. Students solve the problems arising in the laboratories by brainstorming and sharing of ideas.	60
	7) Student presentations: each group of student analyses the data and presents the results to the class, including data tables, graphs comparing control and experimental groups, and conclusions. Other groups should participate by sharing ideas in the discussion.	35
	8) Assignment: students are assigned lab write-up reports.	5 (and home work)
3	9) Reading an article: students are assigned the biological control article to read and must answer the critical questions.	30
	10) Concept mapping: each group of students draws the concept map.	30
	11) Interview: teacher interviews individual student with concept questions.	45 (after class)
	12) Project assignment: students apply the knowledge gained to design a proposal for a biological control project to be presented in group report.	10 (and after class)
	13) Post-test: students take post-test examination (multiple choice questions)	20
	14) Attitude survey: students answer the questionnaires in the attitude survey form.	10

Teaching sequences

The teaching sequences followed a lesson plan based on the experiential learning cycle of Kolb and Fly (1975) (Table 1). The process started with a pretest to determine the prior knowledge of the students in both groups. The students in experiential learning group discussed and answered critical thinking questions, practised laboratory techniques, conducted experiments and read an article. They practised both observation and reflection that would lead to construction of the concepts or knowledge learned from the performed activities. At the end of the activities, they were asked to apply the constructed knowledge in a new situation, i.e., the designing of their own science projects. After the activities, student conceptual understanding and critical thinking were measured by the constructed assessment tools, and student attitudes towards the hands-on activity were determined.

Development of a hands-on activity concerning biological control of plant disease by yeast
The hands-on experiment was based on research on biological control of anthracnose disease in chilli fruits by yeast (Chanchaichaovivat et al. 2007). After discussing organismal interrelationships in the ecosystem with special emphasis on biological control (about 20 min), the teacher demonstrated the methods used to control chilli anthracnose disease by antagonistic yeasts (25 min). The methods included isolating yeast antagonists from fruits, making wounds on fruit samples, culturing of yeast antagonist and fungal pathogen in the laboratory, and inoculating these microorganisms on agar plates and on fruit sample wounds. Student subgroups then discussed the design of their own experiments (25 min), e.g., how to choose fruit samples for isolation of yeast antagonists, how to choose fruit samples for use as hosts, and how to choose a fungal pathogen strain for a biological control test (the teacher prepared a broad range of fungal pathogens for the experiment, e.g., *Colletrotrichum* spp, *Botrytis* spp., *Rhizopus* spp.). The students developed their own hypothesis for the experiment and defined the variables (such as concentration of yeast or fungal pathogen, type of host plant, temperature, incubation time, etc.). They also discussed and designed procedures for collecting and analysing the data. On the second day of activities, group of four students performed the experiment according to their own plans (60 min), recorded the data, and prepared a laboratory report. Meanwhile, the teacher acted as a facilitator, and the students discussed experimental results and problems, brainstormed, and shared ideas.

Data collection and analysis

• ***Pretest and post-test***

Student prior knowledge in both the traditional teaching and experiential learning groups was evaluated with a conceptual pretest, consisting of fourteen multiple choice questions. The pretest was given for 20 min at the beginning of the teaching sequence, and the same questions were used for post-test at the end of teaching sequence. The multiple choice questions were constructed based on the six-level cognitive domain of Bloom's taxonomy in the cognitive domain (Bloom, 1956). The conceptual test was validated by the Index of Consistency (IOC) method (Wainer and Braun, 1988).
Before the test was given to the students, the comments from two experts in biology from the secondary school and an expert in the field of microbial ecology from university were used to fine-tune the format and structure of the test; the test was then tried out with 100 eleventh grade Thai students who had previous knowledge on organismal interrelationships. The test was also analysed for the Cronbach alpha value (Cronbach, 1951), level of difficulty, discrimination power, intellectual level, and overall reliability.

• ***Assessment for critical thinking skills***

After finishing the biological control experiment, the students spent 20 min in class reading an article on "Biological Control of Postharvest Diseases" and answering the questions that would reveal their critical thinking skills. These questions (Table 3) focused on six thinking abilities, i.e., the abilities to interpret, analyse or evaluate, infer, explain, and self-regulate, which are the main components of critical thinking skills according to the assessment tool of Critical Thinking Scoring Rubric (Facione and Facione, 1994). The six critical thinking skills demonstrated in the student answers were rated as 1=poor, 2=fair, 3=good, and 4=very good. Additionally, each student's critical thinking on the biological control method was assessed using an open-ended question: "Why do you prefer to grow plants using biological control rather than chemical pesticides?"

- ***Concept mapping***

Each subgroup of four students in the experiential learning group was asked to brainstorm and construct their "concept maps" including concepts on “organismal interrelationship in biological control of plant diseases” for 30 min. The maps were graded with the scoring rubric of Moni et al. (2004) with three probing dimensions, i.e., content, logic and understanding, and presentation. The maximum score of each dimension is 5, and the maximum overall score is 15. A score of 15 indicates that all relevant concepts of organismal interrelationship are correct and have multiple connections; the students clearly understand facts and concepts of organismal interrelationship and have used correct links; the concept map is neat, clear, and legible, with easy-to-follow links and without spelling errors. On the other hand, a total score of 3 indicates that the interrelationship concepts are wrong, are incorrectly linked, and use incorrect linking words.

- ***Conceptual interviewing***

Four students each from the experiential learning and traditional teaching classes (a total of eight) were randomly sampled for semi-structured interviews after the third day (Table 1). Each 45-min interview, in which students were asked five questions (Table 5), was audiotaped and noted for the additional data. The interview questions were designed to measure conceptual understanding about organismal interrelationships and modes of action in the biological control of plant diseases. The scoring rubric for conceptual interviewing had four levels: very good (all answers are clear and accurate), good (some answers are accurate), fair (some or all answers are ambiguous), and poor (all answers are incorrect).

- ***Designing project proposal***

To extend their knowledge, each group of four students in the experiential learning group was asked to design a science project, which they would perform in the following two semesters. Teachers provided guidance about techniques to ensure that the projects would be plausible. To write their project proposals, students used information from websites, organisations, journals, and experts. Furthermore, students and advisory teachers met each week to discuss project progress. After one month, the students presented their proposal to project committees (three teachers), who suggested changes to the project or solutions to project problems.

The project proposals were assessed with a scoring rubric from Handerson (1997) with minor modifications. The rubric assessed abilities to identify the objectives, hypothesis, variables, and control. The rubric also assessed the proposed procedure and data interpretation. Each attribute was assessed in scores at three intervals: 10-8 points = above standard, 7-5 points = at standard, 4-0 points = below standard.

- ***Student attitudes towards the biological control experiment***

Student attitudes towards the hands-on yeast biological control experiment were investigated by using a questionnaire with a five-point Likert’s scale (5 = strongly agree, 4 = agree, 3 = neutral, 2 = disagree, 1 = strongly disagree). The students were also asked to assess the benefits of participating in the biological control experiment (Table 8).

- ***Statistical analysis***

The data from the two groups, experiential learning and traditional teaching, were statistically analysed by Independent-samples *t*-test analysis (P<0.05) of SPSS software (version 10.0 for Windows, SPSS Inc., Chicago, Illinois, USA). The significance at $P < 0.05$ was used for mean separation.

Results

Conceptual understanding of biological control and organismal interrelationships

According to the pretest scores, prior knowledge of biological control and organismal interrelationships did not differ between the students in the traditional and experiential learning groups (Table 2). At the end of the teaching sequences, however, the scores were significantly higher in the experiential learning group than in the traditional group (Table 2).

Table 2. Pretest and post-test scores on conceptual understanding in the experiential learning and traditional lecture groups

	Experiential learning group		Traditional lecture group	
	Pretest	Post-test	Pretest	Post-test
Mean score (max =14 points)[a]	4.27a	8.73b	4.58a	6.68c
Standard deviation	1.38	1.73	1.63	1.68
Number of students	33	33	31	31

[a]Mean values followed by different letters are significantly different according to t-test analysis (P<0.05).

Critical thinking skills

Students answered six questions about an assigned article on biological control of plant diseases. For each question, mean comparison of test scores by Independent *t*-test analysis revealed that students in the experiential learning group had significantly higher critical thinking skills than those in the traditional group (Table 3) (P<0.05). Students in the experiential class had good to very good thinking abilities (scores: 2.95-3.74) whereas those in the traditional class had poor to fair thinking abilities (score: 1.14-2.45). Based on the average score for all six questions, the critical thinking skills of the experiential learning group were good (score of 3.41), while those of the traditional group were fair (score of 2.25); these means were significantly different (P<0.05). Among the six questions, the lowest score was in the abilities to explain the assumptions and procedures and the highest score was in fair-mindedness (Table 3).

In addition, all 33 students in the experiential learning group answered open-ended questions related to the real situation, i.e., why do you prefer to control plant disease with biological control rather than with chemical pesticides? Students were allowed to write more than one answer. The student answers and frequencies were as follows: to improve human health (n=27) and food quality (n=21); to reduce negative impacts on the food web (n=16); to reduce soil pollution (n=18), water pollution (n=10), and air pollution (n=8); to decrease cost of disease control (n=4). The results suggested that students were more concerned with food quality than with environmental problems.

Table 3. Analysis of critical thinking skills based on answers to critical thinking questions

Critical thinking questions	Scores/Levels[a] (Means ± SD)	
	Experiential learning group	Traditional lecture group
1) What are the characters of the microorganisms that support the ability for postharvest diseases control? (Inference ability)	3.73 ± 0.734	2.29 ± 0.632
2) Suppose you disagree with the use of biological control for postharvest diseases. Give reason for your disagreement. (Argumentative ability)	3.18 ± 0.532	2.05 ± 0.951
3) What are the weak and strong points of biological control method? (Analysis and evaluation ability)	3.28 ± 0.842	2.30 ± 0.942
4) Can all microorganisms on fruit surfaces protect pathogen infection? Give good reasons for your answer. How do you prove your answer? (Abilities to cite knowledge, explain and prove)	2.95 ± 0.646	1.14 ± 0.531
5) Is the biological control of postharvest diseases suitable for the present situation? Give good reasons for your answer. (Fair-mindedness)	3.74 ± 0.603	2.38 ± 0.792
6) What is the highlight of this article? (Ability to draw warranted conclusions)	3.67 ± 0.728	2.45 ± 0.640
Holistic score	3.41 ± 0.681	2.25 ± 0.714
Number of students	33	31

[a]The levels of critical thinking skills: 1=poor, 2=fair, 3=good, and 4=very good

Concept map of biological control of plant diseases

To evaluate their conceptual understanding, subgroup from both the experiential learning and traditional groups was asked to draw a concept map on biological control of plant diseases. To create a map, four students in each subgroup shared ideas and discussed extensively. Concept maps of the traditional lecture group generally showed less complex conceptualisation than those of the experiential learning group, which could be seen even with a brief consideration of map size. Randomly selected concept maps, one each from the traditional or experiential learning groups, are illustrated in Figures 1 and 2. More elements and linking words are evident in the map from the experiential group than in the map from the traditional group.

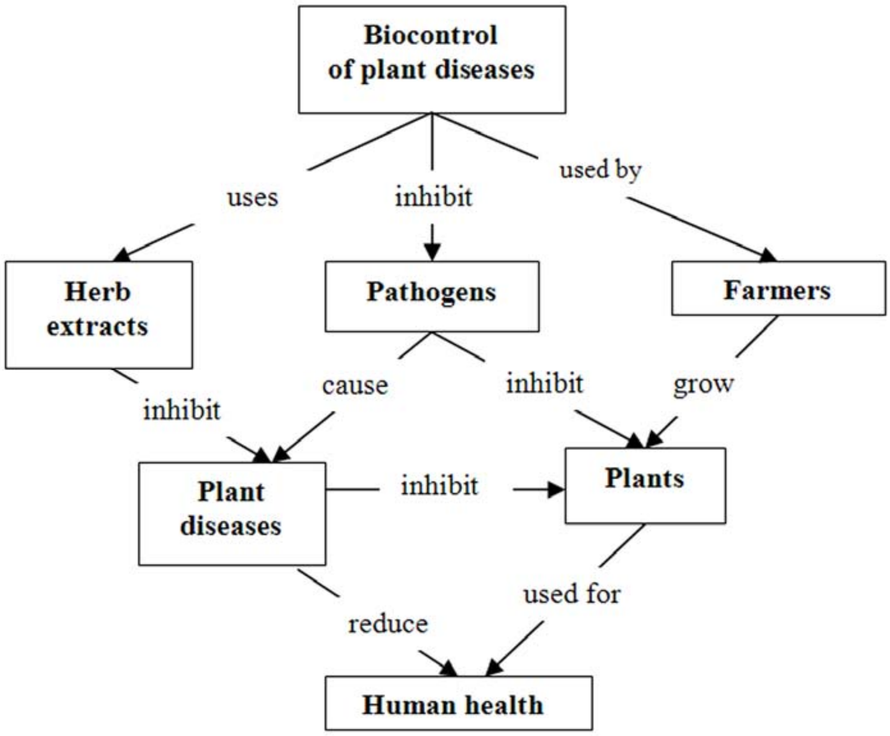

Figure 1: Concept map of biological control drawing by traditional lecture group

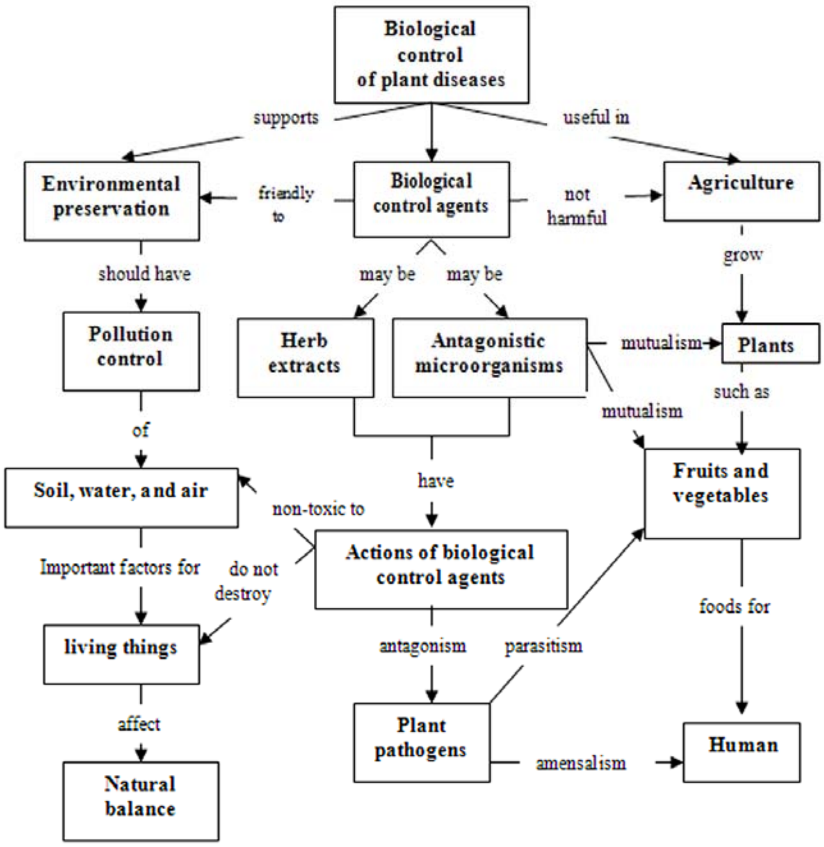

Figure 2: Concept map of biological control designed by experiential learning group

Most importantly, concept maps of the experiential learning group showed the most desired characteristic of the teaching and learning process, i.e., concept interconnection. The concept maps did not appear as fragments but as parts of a whole, whose interconnections are crucial for understanding the content in its more complex sense, which includes generalisations, abstractions and content disposition by order of relevance and meaning. For instance, the concepts of interrelation of the biological control of plant diseases, agriculture, and environment were clearly demonstrated

(Figure 2) with details of the sub-links to microorganisms related to plants, pathogens, humans, and pollution. An analysis of the interconnections between the concepts on the maps indicated that the experiential group had a better understanding than the traditional group. Moreover, the concept map from the traditional group showed confusion in concept interconnection and often used the word “inhibit” to indicate a relationship, while the concept map from the experiential group indicated interconnection with more specific terms like “mutualism”, “parasitism”, “antagonism”, "amensalism," etc.

The average scores of the concept maps were significantly higher from the experiential group than from the traditional group (Table 4). According to the scoring rubric assessment tool of Moni et al. (2004), most concepts of organismal interrelationship in biological control of plant diseases were correct and had multiple connections (score 4.39) in the concept maps of the experiential learning group; understanding of facts and concepts is demonstrated by few erroneous links (score 4.01). Moreover, the concept map of the experiential learning groups was neat, clear, legible, had easy-to-follow links, and had few spelling errors (score 3.92). In the traditional group, only a few relevant concepts of organismal interrelationship in biological control of plant diseases were correct and connections were few (score 2.15). Facts and concepts in the concept map of the traditional group had some significant errors, and although the concept map was neat and legible, links were difficult to follow and there were more spelling errors (Table 4).

Table 4. Evaluation of concept maps with scoring rubric (Moni et al., 2004)

Criteria	Scores/Levels (Means ± SD)	
	Experiential learning group	Traditional lecture group
1) Content[a]	4.39 ± 0.781	2.15 ± 0.954
2) Logic and understanding[a]	4.01 ± 0.921	2.46 ± 1.056
3) Presentation[a]	3.92 ± 1.482	2.88 ± 1.045
Total score[b]	12.32 ± 0.956	7.49 ± 1.067

[a]Maximum = 5 points.

[b]Maximum = 15 points.

Interviewing for conceptual understanding

After the teaching sequence was completed, conceptual understanding of students in both experiential learning and traditional lecture groups was assessed by semi-structured interviews. The interviewing questions on organismal interrelationship in biological control of plant diseases were divided into three parts to probe each concept (Table 5). The results showed that understanding was significantly greater in the experiential learning group than in the traditional group (P<0.05). In the experiential learning group, students had good to very good levels of conceptual understanding of organismal interrelationship and biological control, but the scores of basic concepts regarding the modes of action between organisms were a bit lower. Students in the traditional group also had less understanding about the mode of action than about the other two topics (Table 6).

Table 5. Evaluation of student answers to the interview questions

Interview questions	Probing concepts	Evaluating level/score [a] (Mean ± SD)	
		Experiential learning group	Traditional lecture group
1) When plants were infected by the pathogens, what could be the interrelationships between plants and pathogens?	•Basic ideas concerning the concept of organismal interrelationship	3.70 ± 1.245	2.19 ± 1.312
2) What types of relationships are included in this situation?		3.14 ± 1.081	1.39 ± 1.167
3) Give examples of the plant pathogens.		3.63 ± 1.194	2.57 ± 1.025
4) How does one organism inhibit the growth of another organism?	•Basic concept regarding to the modes of action between organisms	3.01 ± 1.222	1.62 ± 1.298
5) How does the pathogen damage the plant host?		3.11 ± 1.047	1.38 ± 1.391
6) What is the meaning of biological control and its application?	•The concept of biological control	3.75 ± 1.232	2.83 ± 0.928
7) What are the properties of the biological control agents?		3.42 ± 1.098	2.65 ± 1.042
8) Give examples of the biological control agents.		3.68 ± 1.103	2.43 ± 0.957

[a]The level/score of conceptual understanding based on the scoring rubric: level 4 (very good) = all answers are clear and accurate; level 3 (good) = all answers are relatively clear; level 2 (fair) = some or all answers are ambiguous or indicate misconception of the relationship between concepts; and level 1 (poor) = the student cannot answer all questions.

Some answers of students from the experiential group reflected the benefit of the hands-on activities in helping them to answer these questions. For example:

- *Well, from my experience in doing the biological control lab, the plant pathogen may be the mold occurring on the fruit sample.*
- *Yeah, I realise that some microorganisms such as yeasts can be used as biological control agents, from doing this lab.*

- *I'm sure that the yeast antagonists have to secrete some substances or compete for the nutrients with the plant pathogen, so that they can reduce the growth of pathogens.*
- *Yeah, to decrease chemical contaminations in agriculture, biological control is the good method for controlling plant pathogens resulting in reduction of the plant diseases as observed in our lab.*

During the interviews, some students enthusiastically indicated that "they would like to do more biological control investigation":

- *Teacher, may I test whether the bacteria can inhibit the pathogens on chilli or not? I have learned about its ability from reading some agricultural magazines.*
- *This biological control experiment is very interesting to me. Ahh, I want to learn how to apply it commercially?*
- *I'm excited when I saw yeast cells and mold mycelium under microscope or able to culture them to become colonies on plate. Well, I decide to study them more in my science project.*

In addition, the students indicated that the article on biological control of plant diseases helped them to understand biological control and its role in the environment:

- *Yeah, microorganisms such as bacteria and yeasts can inhibit growth of the fungal plant pathogens. I realise from reading the assigned article.*
- *Ahh, I have read the article and in my view, biological control method is very important in postharvest, because it can reduce chemical contaminations on fruits and vegetables.*
- *Yes, organisms can inhibit growth of other organisms by competing for nutrients or producing antibiotics and cell-wall degrading enzymes.*

Project design

Each group of four students in the experiential learning class was asked to apply their knowledge to create a science project as part of their regular course in the next semester. Each group of four students presented a proposal after 1 month of brainstorming and receiving comments from the project committees. The students were interested in using biological control in Thai crops and studying the abilities of the biological control agents. The project titles of the eight groups of students are shown in Table 6.

Table 6. The titles of the student projects in the experiential learning group

Group	Title
1	Control of rhizome rot of ginger during storage by using antagonistic fungi and plant bio-extracts (Piper Betal leaves and Clove extract).
2	Effects of crude extracts from herb (*Andrographis paniculata*) on bacteria causing soft rot in tomato.
3	Investigation and screening of phylloplane yeasts against fruit rot fungus (*Lasiodiplodia theobromae*) on rambutan.
4	Development of fungal spray (*Cordyceps tuberculata*) for controlling worm of cabbage (*Spodoptera exigua*).
5	Effects of fungal strains isolated from herbivore feces on tomato anthracnose caused by *Colletotrichum capsici*.
6	Selection of antagonistic yeasts from fruits and vegetables for controlling green mold (*Penicillium digitatum*) of postharvest orange.
7	Selection of bacterial strain which inhibits *Pythium aphanidermatum* pathogens of root and basal stem rot of soybean.
8	Screening of *Bacillus* strains for controlling potato wilt caused by *Ralstonia solanacearum*.

These project proposals were evaluated according to a content scoring rubric. As shown in Table 7, the tasks were ranked as superior in the attributes of objective, variable and control, and hypothesis. However, the procedure, diagram(s), and data interpretation plan were ranked adequate (Table 7). The holistic quality of the project proposals was ranked as superior.

Table 7. The average scores of each project-proposal component by eight groups of students

Attributes	Mean[a]	SD
Objective	9.12	1.089
Hypothesis	8.10	1.047
Variable and control	8.46	1.194
Procedure	7.05	0.920
Diagram(s)	7.37	0.786
Data interpretation plan	6.83	1.232
Holistic score	8.32	1.057

[a]The score ranges: 0-4 = inadequate, 5-7 = adequate, and 8-10 = superior.

Student attitudes towards the biological control experiment

Most students agreed or strongly agreed with the advantages of the hands-on biological control activity (Table 8). Examples of comments from the students are as follows:

- I am lucky to have an opportunity to learn the biological control techniques used in agricultural science.

-The experiment was enjoyable and encouraged good relationship in our group.

-The knowledge from this class can definitely be used in advanced learning of science.

-The experiment promoted awareness of problems from using chemicals in the environment.

-The biology course should have more experiments like this.

Table 8. Student attitudes towards hands-on biological control experiment

Item[a]	Mean [b]	SD
1. The hands-on experiment helped me to understand concepts of organismal interrelationship.	4.17	0.70
2. I had opportunities to practice microbiological techniques.	4.54	0.66
3. The hands-on experiment encouraged me to think scientifically.	4.00	0.51
4. The hands-on experiment increased my understanding of microorganisms.	4.38	0.58
5. The hands-on experiment was interesting.	4.17	0.76
6. I could apply the hands-on experiment to design a science project.	4.25	0.85
7. The hands-on experiment made me want to preserve the environment.	3.88	0.80
8. The hands-on experiment made me think more about the impacts of chemical pesticides on the environment.	3.79	0.88
9. The hands-on experiment made me think about the importance of the relationships between organisms and the environment.	3.96	0.86
10. The hands-on experiment was useful in my daily life.	4.08	0.97

[a]Each item was scored on a five-point Likert's scale (5 = strongly agree, 4 = agree, 3 = neutral, 2 = disagree, 1 = strong disagree) [b]Mean from a total of 33 students

Discussion

This study used experiential activities based on yeast biological control of anthracnose disease in chilli (Chanchaichaovivat et al., 2007) to enhance the learning of secondary biology students. The hands-on, experiential learning activities led to meaningful understanding of organismal interrelationships in real world phenomena and enhanced scientific and critical thinking abilities. By using experiential learning to study biological control, the students were rooted in an investigative framework, i.e., the students performed a biological control experiment and designed science projects. The students developed the questions and found some of the answers by using the scientific process, by thinking scientifically, and therefore by thinking critically. In contrast to the experiential learning activities, the traditional lecture did not engage students in a real world experience. In the traditional lecture, the students learn from the teacher without proving their knowledge in analysing and developing research and without thinking like a scientist. When the course was finished, the critical thinking abilities of the students in the traditional lecture group were inferior to those of the students in the experiential learning group.

According to the four-step model of Kolb and Fly (1975), the experiential learning students in this study gained the maximum possible benefit from each step. In step 1, the students learned techniques used in an experiment on biological control of plant diseases, which then served as a concrete experience for the subsequent activities. In step 2, the students reflected on what they knew from observation on biological control techniques and then shared the ideas for planning and conducting group experiments. The students attempted to analyse the resulting data and discussed the key points. The students used laboratory reports to clarify their understanding and also to practise the systematic presentation of scientific data. In addition, they constructed concept maps (Figure 2), which required each student to critically consolidate their newly gained knowledge. In step 3, the students used their analysis of data to make conclusions and generalisations and to form concepts (Tables 3 and 5). By answering a set of questions, the students realised the importance of the biological control context, what the laboratory experience meant to them personally, and what this kind of research means to everyday life (Tables 3, 5, and 8). This step enhanced high order thinking skills and helped students to construct more sophisticated knowledge or concepts. In step 4, the students expressed what they learned and demonstrated how they applied this knowledge to the new situation. For example, each group prepared a proposal for a science project, and this required that they use critical thinking skills and conceptual understanding obtained from steps 1–3. The students who participated in the experiential learning cycle gradually accumulated the new knowledge on biological control while they attempted to use the scientific process to solve the new problems.

As demonstrated by their improved abilities to formulate answers and explanations of organismal relationships in biological control systems (i.e., parasitism, antagonism, and protocoperation, see Table 2), the experiential learning students obtained a better conceptual understanding than the traditional lecture group. The experiential learning students also demonstrated the complexity of their knowledge in their concept maps, which indicated relationships between concepts related to biological control of anthracnose by yeast (Figure 2 and Table 4). The students in the experiential learning group were able to conceptualise knowledge from the practical work on biological control and showed great interest in what they learned, as demonstrated by their clearer answers to interview questions and by their curiosity to learn more than what was given in the class (Table 5).
Students in the experiential learning group accomplished the main intended learning outcomes, as reflected by their abilities to: pose problems; generate questions; plan and perform the investigations; and formulate, communicate, and defend a proposal. This is not surprising because the experiential learning activities provided opportunities for students to pose their own questions about biological control of plant diseases and plan their own scientific investigation to test their hypotheses. They dared to interpret, analyse, and evaluate the experimental results and presented their work and ideas to the whole class. They expanded the constructed knowledge by following the biological control laboratory with more practical work in their science projects (Table 6). This benefit agrees with previous findings that hands-on experiments increase skill proficiency in the science process (Mattheis and Nakayama, 1988). Hands-on activities have also been shown to increase learning achievements in science (Brooks, 1988). In contrast, the traditional learning group could not transfer concepts learned in the lecture to a real life situation. This was reflected in their limited ability to connect concepts of organismal interrelationships with related concepts, such as the impacts of these relationships on the environment, human life, and natural balance (Figure 1). The poor ability of the traditional lecture students to transfer concepts was also demonstrated in their confused explanations in the interviews. They also lacked experiences in science process skills as shown in their inability to describe methods for testing antagonists of plant pathogens (Table 3). These findings agree with the suggestions of Roberts (1997) and Finn *et al.* (2002) that without the integration of ecological experiments into secondary education, students often fail to grasp the connection between environmental issues and the science of ecology.

In the traditional lecture group, students usually showed little interest in organismal interrelationships. This teaching style also did not support team work and development of communication skills, while experiential learning enhanced both cognition and motivation by encouraging students to think of questions that would lead to active learning and group work (Ault, 1986). More importantly, by performing the biological control experiment in this study, the students linked the learning and thinking abilities together as shown in their ability to answer the critical questions and to design their own science projects. The hands-on activities on biological control not only improved higher order thinking and motivated students to learn current course materials but also increased their intrinsic interest in further learning.

Because critical thinking is the application of scientific thinking, learning how to think scientifically will help students to think critically (Schafersman, 1997). Therefore, experiential learning about biological control helps students to practice critical thinking; both the hands-on activities and designed science projects reinforced their critical thinking skills (Tables 3 and 7). In their laboratory reports, they demonstrated critical thinking by reasonably analysing and evaluating the data and by developing reasonable inferences. Although rating the science projects was not a primary aim of this research, the follow-up study revealed that 90% of the projects succeeded.

The lower critical thinking skills in the traditional learning group may be due to lack of opportunities to perform the practical work, which is one of the activities that can enhance these thinking skills (Barnes *et al.*, 2003). Moreover, the students were only given the concepts by the teacher rather than constructing their own. The low critical thinking skills may result in the inability to solve real-world societal and personal problems. Our results support previous findings (Finn *et al.*, 2002; Thomas, 2005) that traditional instruction actually prevents the development of critical thinking skills, which suggests a serious problem for secondary education when one considers how frequently these traditional methods are used in biology courses. Therefore, the traditional model of instruction must be changed if the goal is to enhance the critical thinking abilities of secondary students.
Our students had positive attitudes towards the hands-on biological control experiment. They indicated that the experiment enhanced their conceptual understanding and science skills and increased their awareness of environmental preservation (Table 8). This was supported by the interviews and answers from the assigned article, which showed reasonable and fair-minded ideas about the importance of biological control in agriculture and about how biological control affects food, human health, and the environment. Moreover, their science projects on biological control of plant diseases not only reflected their high order thinking ability but also indicated their desire to improve the environment and take on social responsibility. The students enjoyed the experiment and looked forward to further investigation. They were excited while observing yeast and fungal cells and asked many questions about microbial habitat, growth, organelles, and roles of fungi and yeast in the environment. Although many different topics can be investigated in school laboratories, biological control has been considered highly interesting and useful by secondary level students and teachers, and has been cited as a top priority for inclusion in the curriculum (Nonnecke, 2001).

This research suggests that experiential learning of biological control can improve student achievement in biology courses. Because biological control is a clean technology and is not harmful to the environment, students should learn how to use it in their daily life. The biological control experiments with microorganisms can be performed with many kinds of vegetables and fruits, and the microbial antagonists can be either bacteria, yeasts, or fungi isolated from natural sources (soil, water, or plants), making it convenient for students to design various science projects. The teachers in secondary school may adopt and adapt these learning activities to improve learning outcomes in their classes, especially to enhance student ability to conceptualise and to think critically. Experiential learning activities with biological control should be used to encourage environmental and social responsibility of secondary students and to promote their abilities to think critically.

Acknowledgement

The funding of this research by Mahidol University Research Grant is gratefully acknowledged.

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