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Full Length Research Paper

Applying problem-based training approach into the training program on industrial ecology and environment

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Abstract

The training program on industrial ecology and environment hosted by Mahidol University is designed to provide an understanding of the principles concepts and practice of industrial ecology, which have direct benefits for the sustainable development of industrial sectors in Asia. In 2011, for the first time, the problem-based training (PBT) approach was used to design the course structure of the 3rd international training course on industrial ecology. Three modules, which are in-class learning, field study (learning by doing), and group discussion (analysis and synthesize idea), were offered as a framework for this course. Fourteen participants from nine participating countries in South Asia, Southeast Asia, and the Middle East joined this training program. Sustainability management of the Northern Region Industrial Estate (NRIE) and community area were delivered as a project study, which referred to the three main issues: 1) water quality of the Kuang river, 2) soil contaminated problem, and 3) community feedback to the NRIE. The results from the training program revealed that industrial activities in the NRIE did not affect the water quality in the Kuang river and soil quality around NRIE area. In addition, the local people who live within or near that area have positive attitude towards the NRIE. This training approach was a challenge for the majority of participants who had not previously been exposed to it. Participant's feedback was overwhelmingly positive. Participant's satisfaction level with the training program had a mean score of 4.92 (out of 5) with all participants agreeing or strongly agreeing that using the PBT methodology can enhance the transdisciplinarity between academics and practitioners, self-regulated learning, and collaboration.

Keywords: Industrial ecology, Problem based training, Sustainability management, Eco-industrial estate.

INTRODUCTION

Since the release of Our Common Future in 1987 and Agenda 21 in 1992, government and industry have emphasized on the concept of sustainability, which embraces the integration of economic, ecology and social dimensions. Industry plays a significant role in the economic prosperity of a country. Rapid industrial growth without environmental concerns has resulted in changing the unsustainable patterns of the natural resource consumption and increasing more pollution. In order to reach the sustainability of industry, the concept of industrial ecosystem, one aspect of the industrial ecology field, has been proposed. The example of an organized form of the industrial ecosystem is an eco-industrial park (Cote and Hall, 1995; Lowe and Evans, 1995).

The concept of industrial ecology has been emerged in Asia developing countries for more than 10 years. Many local institutes, such as university research center and research teams, have contributed to the conceptual knowledge of industrial ecology via training, academic

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studies, and applied research (Chiu and Yong, 2004). In Thailand, the concept of industrial ecology has become widely known since the eco-industrial park concept was introduced to industrial estate 15 years ago. The international training course on industrial ecology and environment, which was organized by the Eco-Industry Research and Training Center (Eco-IRCT), Faculty of Environment and Resource Studies, Mahidol University in Thailand, is a practical training program that applies industrial ecology concept for participants in both Asia developing and undeveloped countries.

The concept of Problem-based Training (PBT), which was applied into the training program on industrial ecology and environment, is adopted from a Problem-based Learning (PBL) concept. PBL is a strategic learning system design that was first developed in the medical field over 50 years ago in response to student dissatisfaction with the lecture format (Gwee 2009, Rogal and Snider 2008). PBL is an active learning model, which focuses on the learning that results from the process of working toward the understanding or resolution of a problem (Yasin and Rahman 2011, Harris and Briscoe-Andrews 2008). It has been widely used in higher education and distributed into a diverse range of disciplines such as engineering (Harris and Briscoe-Andrews 2008, Masek and Yamin 2010), medical education and healthcare (Gwee 2009, Rogal and Snider 2008, Barrows and Tamblyn 1980, Alexander et al 2002), business and entrepreneurs (Hallinger and Jiafang 2011), and etc. However, an implementation of PBL concept into a training program particularly on environmental study has not been observed extensively.

In this article we demonstrated how training program on industrial ecology and environment can contribute to and support the sustainable development of industry. The overall structure for applying the PBL idea based on project study of the training program was presented. The results regarding to the project study obtained from the field investigation were reported. Finally, participants' reactions to the training program were assessed and described.

Overall structure of the training program

The training program on industrial ecology and environment was first initiated in the year 2007 and has been provided every two years. The training course was designed to deliver an understanding of the principle concepts and practice of industrial ecology to participants from different countries in Asia. The overall structure of the previous training programs in 2007 and 2009 focused mainly on teaching and learning in a classroom. There were some of field site investigations, which were not based on a practice. They were mostly site visiting, which could not deliver to the main objectives of the training program. Of course, this was a significant challenge in organizing committee to expose a new concept idea for the training program. The 3rd international training course on industrial ecology and environment was recently held during July 4th to 22th, 2011. Fourteen participants from nine participating countries in South Asia, Southeast Asia, and the Middle East were selected. The overall structure of the most recent training program was modified. Problem-based Training (PBT) approach was used to designing the course structure, in order to provide a sharing of experiences breakthrough knowledge. The training program structure was framed into three modules, which were in-class learning (Input), field study (learning by doing: Process), and group discussion (analysis and synthesis: Output). The details of each module are expressed as follows:

Module 1: In class learning

This module provided an understanding of the industrial ecology concept and the applications of industrial ecology tools. The first part of this module stated with a country report presentation section where participants had to provide details of a current industrial ecology and the environment problem related to industrial activity in their country including policies and general practices related to its control, solution and management. Subsequently, the participants were given a lecture by various resource persons from Thailand and abroad. The lecture topics covered the basic principle of industrial ecology, life cycle thinking and assessment, eco-industrial park, emission reduction mechanism, and management tools for industrial ecology such as eco-efficiency, environmental standard: ISO 14000. In addition, this module also included the basic principle of environmental management and practice related to industry such as integrated survey, basic laboratory practice for water and soil qualities as well as investigation on behavior of complex integrated human/natural systems through qualitative research and questionnaire. The total duration of this module was 48 hours over the 8 days. The learning from in-class lecturers could help participants understand the concept and application of industrial ecology, which was a very useful input for running the field study in Module 2.

Module 2: Field study

This module, the core part of the training program aimed to provide knowledge learning through field site study. Participants were given a problem assignment using a project-based approach. The project study was delivered using a problem-based training idea, which was a strategy that used a problematic stimulus for participants, acquire knowledge. Participants were present with a problem to solve rather than a lecture to absorb. The

area nearby the Northern Region Industrial Estate (NRIE) in Lumphun province, north of Thailand, was selected to be as the study area for project investigation. The problem assignment offered to participants was "According to the policy of Lumphun province and the Industrial Estate Authority of Thailand (IEAT) that trying to establish an eco-industry, which community around the NRIE can live with industry. NRIE is one of the important industrial estate in the northern of Thailand. If we are the industrial experts, please give suggestions and comments on how to develop NRIE to be an eco-industrial estate". The field study was performed for five days (including two days for travelling from Nakornpathom to Lumphun province, approximately 600 kilometers).

Module 3: Group discussion

The results from field site study were analyzed and synthesized at this module. The combination of knowledge practices from in-class lecture and field study were used for the group discussion. Finally, the result and conclusion received from this training course need to report and present by participants.

Assessment and Course Evaluation

The problem was chosen to help participants explore and learn from a real situation in the focused local area. Participants were encouraged to keep up by self-assessing their skill development using a weekly reflective journal, which is an indirectly tool for helping organizing staffs to monitor participant's progress, as well as taking care of participant's affective domain and thinking skills. In addition, the communication and team-work skills were assessed on the quality of a written report and presentation.

During in-class session, field study, and at the end of course, participants were anonymously required to fill in questionnaires in order to evaluate the training program. The measurement criteria from 1 - 5 score levels (not appreciate to excellent) were used. The questionnaires were separated into three parts, which are (i) Lecturer assessment: questions evaluated the lecturers about general presentation skill, technology usage, ability to answer question, quality of handout material and time keeping, (ii) Field trip assessment: questions evaluating the field study such as the site visits' interest level, relation between site visit and course contents, understanding the knowledge received from the field study and time appropriateness, (iii) Overall assessment: questions evaluating the overall aspect of the training program such as achievement of PBT in delivering the training program and objectives, quality of contents, course design and materials, duration, environment and training program arrangement in general.

FIELD STUDY METHODS

Overview of the Focused Area

Lamphun is one of the northern provinces of Thailand. It is the smallest province in the north with an area of approximately 4,505,882 km^2 or approximately 4.85% of the whole upper northern region. Most areas are plains with the average height about 200 to 400 meters from sea level (Lamphum Provincial Administration Office 2011). There are four rivers flowing through province, which are Ping river, Kuang river, Ta river, and Lee river. Kuang River is a crucial source of water for municipal supply as well as agriculture and industry mostly in NRIE. This river is 115 kilometers long and flows through large catchment areas into the Ping river, merges with others an finally converges to the Chao Phraya River, a major river in Thailand.

Industrial estate in Thailand was developed by Industrial Estate Authority of Thailand (IEAT), which is a state enterprise under the Ministry of Industry. The IEAT is responsible for the development and establishment of industrial estates, where factories for various industries are orderly and systematically clustered together. With industrial estates as an implementation tool, IEAT also serves as a governmental mechanism to decentralize industrial development to provincial areas throughout the country (Industrial Estate Authority of Thailand 2011).

Recently (2011), there are 42 industrial estates distributed in 15 provinces of Thailand. NRIE is an important industrial estate in northern part of Thailand. The total area of NRIE is 2.89 km^2 including general industrial zone 0.57 km^2, IEAT free zone 1.30 km^2, and residential area 0.14 km^2. Presently there are 36 companies located within the NRIE. It can be divided into four industrial categories, which are electrical manufacturing, agricultural manufacturing, food and beverage manufacturing, and construction business (Panyathanakun et al 2012).

Key finding of the focused area

During in-class lecture, participants and academic staffs of the training program started to find out the background information and problem issue of the focused area. The three main issues that supposed to be the key findings for solving the problem assignment were:

1) Water quality of the Kaung river, which is probably affected by community activities and/or industrial activities.
2) Soil contamination from the agricultural activities

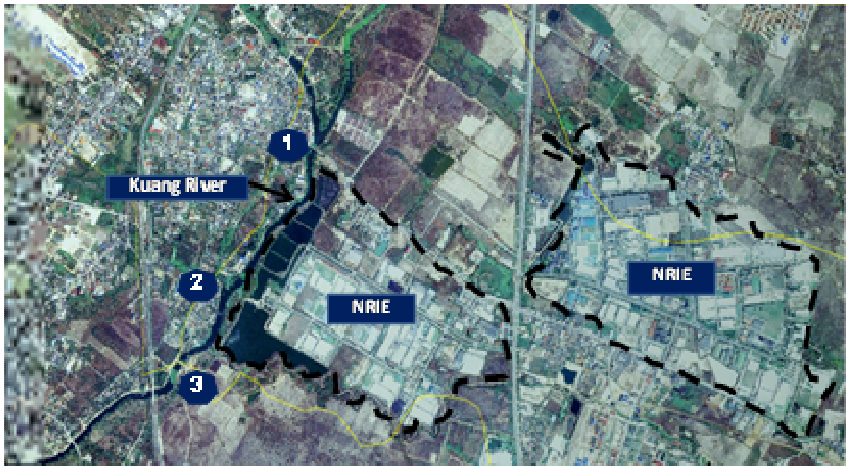

Figure 1. The sampling areas for water quality measurement

and/or industrial activities.
3) Community perception about the impact of NRIE activities.

Sampling and analytical procedures

After the key findings from the area were stated, three different sampling areas, which locate at upper, middle (near the discharge point of the NRIE's waste water treatment plant), and lower Kaung river, were then specified for field site study and data collection. The sampling areas are shown in Figure 1. The surface water quality, soil quality, and community perception of the three different sampling areas were studied. The parameters for investigation of water quality were temperature, water color, turbidity, conductivity, dissolve oxygen, salinity, phosphate, nitrate, and ammonia. Texture, ammonium, nitrate, phosphate, and pH of the top soil and sub soil were investigated as a measurement of soil quality. Due to the short period time of training program and field study, the repeated monitoring in different seasons and analytical procedures were limited. All parameters for investigation of the surface water and soil qualities were carried out using the field measurements and test kits. Lastly, community perception of NRIE on the dimension of economic, health, and environment such as income, job, quality of life, health, and acceptance was observed (Figure 1)

RESULTS FROM THE FIELD STUDY

The results of water quality measurement from three stations (as shown in Table 1) can be summarized in the following points. Water quality of Kaung river could be classified between class 2 and class 3, which is the medium clean surface water resources used for consumption and agriculture, in accordance with Thailand surface water quality standard (Thailand National Environmental Quality Act 1992). Water quality at station 2 (S2), which locates closely to the discharge treated water station of the NRIE, appeared to be better than the water quality at station 1 (S1) and 3 (S3). This finding could reflect the water treatment system quality of NRIE. Differences in water quality results between our monitoring and previous study (Chitmanat and Trichaiyaporn 2010) were observed due to the limitation of field instruments and variation of analytical procedure. The soil textures of study area were loam and clay, which was appropriate for agriculture. High concentrations of phosphorus and ammonium were observed at the top and first sub soil of station 1 and 3. This probably comes from the residual of fertilizer used in agriculture.

The results of community perception about the impact of NRIE activities, which was carried out using in-depth interview method, showed that the economic dimension had strongly affected the community rather than environmental dimension. This finding was confirmed with the local people's positive attitude towards NRIE that comes from an increase in the local economic and job opportunity. Communities were also satisfied with the way that NRIE could help improving the environmental quality by building up awareness and training program.

From the results of field study, it can be concluded that the regional industry of NRIE is not of great importance for an environmental degradation of the focused area. Several factors such as agriculture, community, and industry may have contributed to an environmental distortion of the focused area.

Table 1. Measurement of water quality and classification of surface water quality

Parameters	S1	S2	S3	WQS2	WQS3
Temperature. (^{o}C)	28	29	30	n'	n'
Colour	Brown	Brown	Dark Yellow	-	-
Turbidity (NTU)	31.1	42.4	54.4	<10*	<10*
Transparency (cm)	n.a	50	n.a	30-60	30-60
Conductivity (µS/m)	225	233	222	100-300*	100-300*
Dissolve Oxygen (mg/L)	4.35	5.63	5.10	6.0	4.0
pH	6.9	7.0	6.7	5.0-9.0	5.0-9.0
Salinity (ppt)	0.11	0.11	0.11	-	-
Phosphate (mg/L)	0.042	0.025	0.025	1.0	1.0
Nitrate (mg/L)	0.4	0.5	0.5	5.0	5.0
Ammonia (mg/L)	0	0	0	0.5	0.5
Total dissolved solids (mg/L)	113.8	116.7	110.9	-	-

WQS means Standard of surface water quality from Notification of the National Environmental Board, No. 8, 1994.
WQS2 means Class 2 condition/beneficial usage for aquatic organism of conservation, fisheries and recreation.
WQS3 means Class 3 condition/beneficial usage for agriculture.
* Approximate value.
n' means water temperature do not over natural temperature 3 ºC

Table 2. Measurement of soil quality

Level and Station	Texture	pH	Ammonium	Nitrate	Phosphorous	Potassium
Top soil (10-15 cm from the surface)						
S1	Loamy	7.0	Medium	n.a	Very high	Low
S2	Clay	7.0	Low	n.a	n.a	Medium
S3	Silt clay loamy	5.5	Low	Low	High	Medium
1st sub soil (15-60 cm from the surface)						
S1	Sandy clay loam	7.5	Medium	n.a	High	Low
S2	Silt clay loamy	7.0	n.a	n.a	n.a	n.a
S3	Sandy clay loam	7.0	Medium	Very low	Low	Low
2nd sub soil (60-100 cm from the surface)						
S1	Clay	6.5	Very low	n.a	High	Low
S2	Silt clay	6.5	Low	Very low	Low	Low
S3	Sandy clay	6.5	Low	Very low	Very low	Low

n.a : not available

Table 3. Results from local community interviews

Issues	S1	S2	S3
1. Environment		The quality of environment has decreased slightly in the following ways: 1) certain crops cannot grow, 2) the water quality has generally decreased, and 3) the influx of more people into the province has created solid waste problems	
a. Water	The quality of water has degraded over the years	The quality of water has generally decreased	The quality of water has degraded

Table 3 continue

b.	Air	The ambient air quality has degraded over the years		Air quality has degraded significantly, smog occurrences at night
c.	Climate change	Temperature is no longer stable. It fluctuates frequently. Extreme temperatures (e.g., very high or very low(occurs more regularly.		Temperatures are much warmer than that experienced in the past
2. Income		Overall income has increased	The community's average income has increased because the way of life has changed from agriculture to commercial based. Their traditional agricultural lands have now been converted to cater for commercial dorms and industries	Generally more income than before
3. Job		Job opportunities have increased		More job opportunities for the community
4. Quality of life		The response received was a split/mix between better quality of life and degraded quality of life	The community feels that their quality of life has improved significantly over the years due to the increased income opportunities	Mixed response as to what a better quality of life is?
5. Health		People in the community report some minor health problems but recognizes that NRIE has been involved in providing health services	The community believes that the standard of human health has not changed significantly. The life expectancy of people in the village remains stagnant; however they have seen an increased in the number of chronic disease incidents such as diabetes and heart diseases	A lot of dehydradation incidents
6. Acceptance of NRIE		Acceptance of NRIE was mixed	The community has come from a stage where they have protested against the industrial developments to now where they are beginning to support the developments. This acceptance is shown when the provincial community leaders agree that the northern province will continue to develop as an industrial area	Mixed response on acceptance of NRIE

SUGGESTIONS FROM THE FIELD STUDY

When the data was analyzed during the discussion part of the training program, the suggestions and comments for the sustainability management of industry in NRIE area and local community were proposed as follows:

- Environmental quality such as water, air, and soil, monitoring based on community participation needs to be

initiated and continued.

- Industry in NRIE has to focus on cleaner production and renewable energy in order to enhance a sustainability of area.
- Eco-forum, which consists of important stakeholders such as NRIE staff, local government staff, community, and industry, etc., must be established.
- Small and medium enterprises outside NRIE need to be monitored. Environmental standard such as ISO-14000 and concepts should be introduced.
- Community participation on environmental policy, strategy, and management of the area must be considered.
- Waste management system of NRIE and local community need to be more effective.

Benefits from the Training Program

The training program on industrial ecology and environment based on the PBT learning strategy could well contribute the practical knowledge on industrial ecosystem management to participants, who particularly come from underdeveloped and developing country in Asia. The benefits from the training program included:

- Enhancing participants' understanding on the principles and ideology underlining industrial ecology and its positive impact on and benefits to the environment which is very useful for sustainability management of industry in their countries.
- Creating new opportunities to make collaboration among participating countries
- Delivering the transdisciplinarity (knowledge and experiences sharing) between academic and practitioners.
- Acting as a catalyst for sustainable development of industrial sector in Asia.

Participant Feedback

Participant feedback to the lectures in each topic was extremely positive with an average score of 4.73 (out of 5). The average scores from the field study and overall training program were 4.96 and 4.76 , respectively. The field study and overall evaluation of the training program from participants indicated a high level of contentment that the training program could deliver a knowledge, skill, and collaboration.

At the end of the training program, the training staff sought feedback from the participants that evaluated satisfaction of the overall training program and the PBT model. The evaluation form contained questions regarding learning and benefit from the PBT training program. Participant feedback was overwhelmingly positive and demonstrated the impact of teaching, field study, and learning style on participant outcomes. In particular, the overall participant satisfaction with the PBT program had a mean score of 4.92 (out of 5), with all participant agreeing with the statement "PBT is very effective for focused learning and understanding of the industrial ecology concept".

DISCUSSION

Applying the PBT to the training program on industrial ecology and environment can improve participants' understanding of the concept of industrial ecology and practice in environmental management particularly on the development of eco-industrial estate. From this example we have found findings and limitations that need to be taken into account when applying the PBT to a training program. However, some of these limitations can be seen as fruitful avenues for future development of the training program.

The time period for training was limited. This approach in the teaching and learning was rather different from the normal approach in school or university. In order to provide an understanding of the principle concept and basic idea of industrial ecology, in-class lectures had to be set in the first week of the training program and qualified for delivering all of important contents related to the training program's title. Time for each in-class lecture topics was limited to three hours. Thus, this time constraint pressured all lecturers to deliver the entire contents on their own topic including the current information that may not available in text books within the limited time (Rogal and Snider, 2008). Academic staffs had to play strongly encourages participant-learning after the every in-class lecture has ended. Text books, articles, and internet accessing had to be provided in order to allow participants to seek out the information that they did not know.

It is important to realize here that the PBT approach applied to the training program was developed in regard to the principles for higher education for sustainable development, which comprised of interdisciplinarity, transdisciplinarity and self-regulated learning (Steiner and Posch, 2006). Interdisciplinarity can be expressed as a combination of knowledge from different fields in order to develop core competences for solving different kind of problems. Transdisciplinarity involves intense interaction between academics and practitioners in order to promote mutual learning process between them. Self-regulated learning means that learners are meta-cognitively, motivationally, and behaviourally active participants in their own learning process and self-generate thought, feelings, and actions to attain their learning goals. In order to reach the goal of higher education for sustainable development, a focused problem was required to be based on the interdisciplinary concept idea, which could lead to the development of the transdisciplinary project study. The focused problem was

also needed to specify the problem with regard to the complexity of the study area and the potential underlying theoretical concepts. With transdisciplinary project study, research and teaching activities could be integrated in a way that leads to a self-regulated learning between the training program staffs, field lecturers, and participants. The interdisciplinary group of academic staffs and field lectures merely play the role of facilitator, which can support participants to meet the principle goals by providing some basic information, supervising the process of working on the project study, and encouraging the use of broad range of knowledge, skills and abilities for solving problem. It was suggested that local experts such as local government staff and industrial estate officer need to be considered in the field lecturer team. Academic staffs and field lecturers including the local experts must be recruited from different fields, such as industrial ecology, industrial engineering, environment science, natural resource management, and social within the context of an environmental study.

Applying the PBT to the training program can enhance participants' understanding and their practice on the industrial ecology concept. Moreover, collaboration and networking among participants and training staffs was established during the field study and discussion section. The challenges in applying PBT to the training program were the monitoring of participations progress and the implementation of PBT to other training program topics.

CONCLUSION

Industrial ecology is an interdisciplinary field that focuses on the sustainable combination of business, environment, and social. It provides a useful system perspective to support sustainable development of industry while assuring shareholder's value creation. This article demonstrated how PBT can be applied to the practical training in order to deliver the transdisciplinarity, self-regulated learning, and collaboration. Applying PBT for training program on industrial ecology and environment offered very useful insights. Sustainability management of the NRIE and community around NRIE area was used as an exemplary project study. The output of training program particularly from field study illustrated a useful data that could guide future research on the environment improvement around NRIE area and the development of NRIE's eco-industrial estate. Lastly, the training program contributions to knowledge in the area of industrial ecology can be a driving force leading to the sustainable development of industry.

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REFERENCES

Alexander JG, McDaniel GS, Baldwin MS, Money BJ (2002). Promoting, applying and evaluating problem based learning in the undergraduate nursing curriculum. Nursing Education Perspectives 23: 248-253

Barrows HS, Tamblyn RN (1980). Problem-based learning: An rigorous to medical education. New York: Springer: 1-19.

Chitmanat C, Trichaiyaporn S (2010). Spatial and temporal variations of physical-chemical water quality and some heavy metals in water, sediments and fish of the Mae Kuang river, Northern Thailand. Int. J. Agric. Biol. 12: 816-820

Chiu ASF, Yong G (2004). On the Industrial Ecology Potential in Asian Developing Countries. J. Cleaner Production 12: 1037-1045Cote RP, Hall J (1995) Industrial parks as ecosystems. J. Cleaner Production 3(1, 2): 41-46

Gwee MC (2009). Problem-based learning: A strategic learning system design for the education of healthcare professionals in the 21st century. Kaohsiung J. Med. Sci. 25: 231-239

Hallinger P, Jiafang L (2011) Assessing the instructional effectiveness of problem-based management education in Thailand: A longitudinal evaluation. Management Learning. Doi: 10.1177/1350507610388596

Harris AT, Briscoe-Andrews S (2008). Development of a problem-based learning elective in "green engineering". Education for Chemical Engineering 3: e15-e21

Industrial Estate Authority of Thailand (2011). http://www.ieat.go.th. Accessed 15 November 2011

Lamphum Provincial Administration Office (2011). Lumphun province. http//www.lumphun.go.th. Accessed 25 October 2011

Lowe E, Evans LK (1995). Industrial ecology and industrial ecosystems. J. Cleaner Production 3 (1, 2): 47-53

Masek AB, Yamin SB (2010). Problem based learning: A review of the monitoring and assessment model, 2010 2nd International Congress on Engineering Education: 171-175.

Panyathanakun V, Tantayanon S, Tingsabadh C, Charmondusit K (2012). Preliminary study on the community-based-eco-industrial estate development of northern region industrial estate, Thailand. 2012 International Conference on Asia Pacific Business Innovation and Technology Management (APBITM Spring 2012)

Rogal SMM, Snider PD (2008). Rethinking the lecture: The application of problem based learning methods to atypical contexts. Nurse Education in Practice 8: 213-219

Steiner G, Posch A (2006). Higher education for sustainability by means of transdisciplinary case study: an innovative approach for solving complex, real-world problems. J. Cleaner Production 14: 877-890

Thailand National Environmental Quality Act (1992). Surface water quality standard in Thailand. Royal Goven Gazette 111 Part 16D, dated 24th February, 1994

Yasin RM, Rahman S (2011). Problem oriented project based learning (POPBL) in promoting education for sustainable development. Procedia Social and Behavioral Sciences 15: 289-293