A new instructional model using the integrated 5Es inquiry cycle and Geographic Information System (GIS) to enhance students' understanding of the nature of science

Joompot Poomsripanon & Yaowaluk Chitramvong

Mahidol University
Bangkok, Thailand

ABSTRACT: The purpose of this study is to enhance undergraduate students' understanding of the nature of science by using an appropriate instructional model. The new instructional model was developed for ecology laboratory instruction and uses a Geographic Information System (GIS) and the 5Es inquiry cycle on the study of mollusc distribution and diversity. Two classes of undergraduate students (n=60) were divided into two groups and participated in a new instructional model group (n=30) and in a traditional instructional group (n=30). After six weeks of participation, both groups' scores regarding their understanding of the nature of science were analysed utilising statistical procedures of the analysis of covariance. The results indicated that the new instructional model enhanced students' understanding of the nature of science. The *understanding of the nature of science* score of those students who participated in the new instructional group was significantly higher than for the traditional group at the 0.05 level of significance. Moreover, those students who participated in the new instructional model expressed that they were more fun to participate in, and that the learning activities and concepts made more sense in this form.

INTRODUCTION

Scientific literacy comprises three constitutive dimensions, namely:

- The nature of science;
- Science content knowledge;
- The impact of science and technology on society [1].

While an impressive body of content knowledge is associated with science courses, there is more about the science that students should learn. To be become a fully science-literate person, a student should improve not only his/her science content knowledge, but also other dimensions of scientific literacy. Students' understanding of the nature of science has been studied for more than 30 years [2]. However, these studies focused on middle and high school grades [3]. Few studies have investigated undergraduate students' understanding of the nature of science.

It has been suggested that, in order to complete the science education experience, instructors should give students the opportunity to learn about the very nature of science, not just content knowledge [4]. The National Research Council has also suggested that students should develop an understanding of what science can and cannot do, and how science contributes to culture [5]. The nature of science reflects on how science tends to differ from other modes of knowing. The nature of science has been laid out as three principal subjects that incorporate: scientific world view, scientific inquiry and scientific enterprise [6].

One challenge for teachers is to transform the classroom from a traditional one wherein students look for affirmation of the right answer from their teacher, to one wherein the teacher empowers students to determine for themselves whether they have offered an acceptable explanation that is supported by

their evidence and through their inquiry, rather than by an authority [7]. The inquiry process is a learning strategy that fosters the scientific literacy [8]. One report affirmed that laboratory experiences are considered as the primary mechanism for providing first hand experience and, therefore, assumed to improve students' understanding of the nature of science [9].

Thus, understanding the nature of science, which is one of the three dimensions of scientific literacy, should also be improved by using an appropriate learning topic with the inquiry instructional model through the laboratory. The 5Es learning cycle is a model for structuring a science lesson that is based upon constructivist learning theory and research-based best practices in science pedagogy and cognitive psychology. It is a recursive cycle of the distinctive cognitive stages of learning that includes engagement, exploration, explanation, elaboration and evaluation. Therefore, the 5Es inquiry cycle was considered as the instructional activity in this study.

The topic, *Diversity and Distribution*, is one of the most important topics in the ecology laboratory. Understanding diversity and distribution is not only necessary for study in the community and ecosystem, but also stimulates students' awareness of the importance of the diversity and distribution of organisms that illustrates their bountiful community. An awareness of diversity and distribution also leads to awareness of the importance of the conservation of natural resources. The diversity and distribution of organisms shows the complexity of the food web, and the richness of natural resources in ecosystem that has caused community stability.

Generally, studies in biodiversity use three indices, specifically the Shannon-Wiener index, species richness and species evenness to measure a species' diversity. These three indices have been used as a measure of diversity in this study. In a traditional laboratory, students are assigned to collect data in

the study area, and then count and identify organisms they have collected. Students then have to calculate the ecological values (diversity, richness and evenness) and interpret those values based on ecological theory. Common questions raised are: *What organism is appropriate to be used as a subject?* and *What is an appropriate innovation to improve the diversity and distribution laboratory?*

It has been suggested that the mollusc is an appropriate freshwater fauna to be studied in various topics of ecology. Molluscs are abundant in many types of freshwater environments, and are relatively easy to collect and identify [10]. As a major biota, molluscs form an important link between the primary detritus at the base of the food web and consumers at the higher trophic levels [11]. Moreover, their large abundance and biomass indirectly play a significant role in nutrient cycling [12]. In addition, in the ordinarily study area, there are many freshwater reservoirs that are used for agriculture, irrigation and household consumption. Therefore, molluscs are appropriate organisms to be used in the diversity and distribution laboratory instructional model.

A Geographic Information System (GIS) that uses a coordinate system or geo-reference has proved useful in data collection, data analysis and data presentation. Nowadays, a GIS has become an increasingly useful tool in many natural resource disciplines. A GIS is able to be used for many purposes. Based on the same coordinates, the presentation may be through pictures, symbols or characters. GIS technology can also explain geographic reality, such as the location of the object or place by exact geo-coordinates, the shape of the object or place, and display the spatial data of the object or place so that it can be located on all sides. Because of a GIS' attributes, the data analysis and imitation model can be displayed in various ways; these can provide various answers so that the best one can be selected. A GIS helps the ecologist to avert any damage that can result from using traditional field study techniques. So, it will not harm nor damage the real area [13]. GIS attributes can be utilised as tools for various purposes, such as for an ecology laboratory on diversity and distribution, so that almost all laboratory studies are field studies. So a GIS is an appropriate tool to use in the laboratory. By integrating the instructional topic, *Diversity and distribution of freshwater molluscs*, the 5Es inquiry learning model and a GIS, a new instructional model was constructed on *The Study of Molluscs Distribution and Diversity by Using Geographic Information System*. The new instructional model will be used as a tool to improve students' scientific literacy in the dimension of *the understanding of the nature of science* in this study.

METHODOLOGY

Research Sample

Students were randomly selected and divided into traditional and new instructional model groups, with 30 students in each group. The traditional group attended a traditional ecology laboratory on distribution and diversity, whereas the new instructional model group attended a laboratory that emphasised the 5Es learning cycle that incorporated a GIS as a study tool in a diversity and distribution laboratory. Both groups were pre-tested and post-tested using a scientific literacy test in the dimension of understanding of the nature of science. Students' post-test scores of understanding of the nature of science were analysed and compared between the two groups. The data were analysed using *SPSS* software for

Windows 11.5, with the significance level at 0.05 for an analysis of covariance using pre-test scores as the covariance.

Research Tool

The tool used to assess students' understanding of the nature of science was the scientific literacy test in the dimension of understanding of the nature of science. The test was modified from the test of basic scientific literacy on the nature of science in the part of the nature of science [14]. The test contained three parts: *scientific world view* (nine items); *scientific inquiry* (18 items); and *scientific enterprise* (15 items). The Item Objective Congruent (IOC) technique was utilised to validate the test; all items' average scores from three experts were ≥0.5. The test was tried out by 230 undergraduate students. The internal consistency of the test items was analysed using Cronbach's alpha coefficient (internal consistency), which was found to be from 0.80-0.86. The reliability overall of the 42 test items was determined as 0.92.

Instructional Model

The GIS, 5Es learning cycle and describing the nature of science as found in the National Science Education Standards were integrated into the new instructional model [5]. Figure 1 illustrates the instructional model of this study.
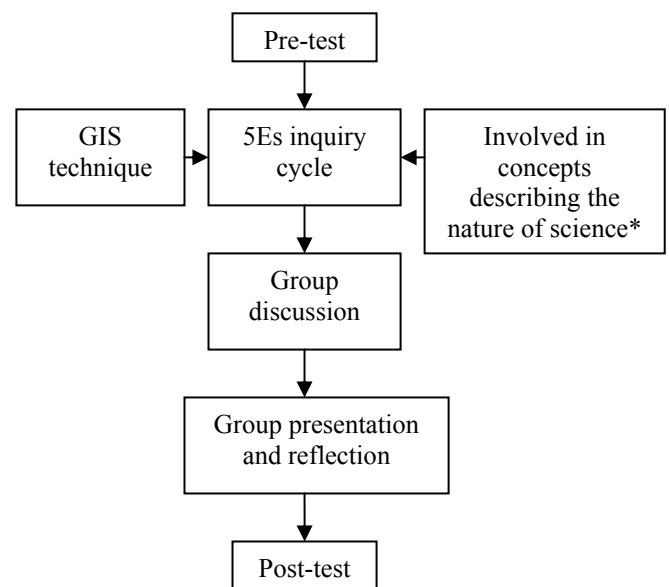

Figure 1: The instructional model of the study.

*Note: Concepts of the nature of science for the fully scientific literate person are: scientific explanations are based on empirical observations or experiments; scientific explanations are tentative; scientific explanations are historical (past explanations are the basis for contemporary explanations; scientific explanations are probabilistic; scientific explanations assume cause-effect relationships; scientific explanations are made public; scientific explanations are limited; and scientific ethics (ie system of morals) is concerned with, among other things, the possible harm that could result from scientific experiments.

ACTIVITIES

Basic Concepts Study

After the pre-test, both groups were instructed about the diversity and distribution of organisms, the calculation of

diversity using the Shannon-Weiner diversity index, species richness and evenness, and the interpretation of these values.

Identification Practice

Both traditional and new instructional model groups were taught about the use of the mollusc identification key following Brandt, Chitramvong, Kaewjam and Upatham et al [15-18].

The study emphasised using the mollusc shell to identify the mollusc species. Students were educated over one week in the use of the mollusc identification key until they could identify molluscs species from the mollusc shell shape, shell size, and/or other shell properties based on the identification key.

GIS Study

Students were required to study the basic techniques of a Geographic Information System (GIS) using a Global Positioning System (GPS) to record the coordinates of each sampling point; transferring the data to the GIS software program, and for data analysis and presentation. They were required to spend two weeks practicing with a GIS until they were able to utilise a GIS as a tool for their data collection and presentation of this data as a GIS map.

Traditional and New Instructional Model Group

Students in the traditional group attended a traditional ecology class of diversity and distribution, whereas students in the new instructional model group were divided into smaller groups with three students in each group; they then engaged the new instructional model that contained the activities described below.

NEW INSTRUCTIONAL MODEL ACTIVITIES

5Es Learning Cycle

Engagement: Pre-Laboratory Discussion

The teacher showed an example of GIS maps of mollusc distribution in the various study areas to students. They were then asked the following question: Q1: *From your basic GIS knowledge, can you explain how to create this GIS map?*

The teacher gave students' time to consider, discuss and share their ideas about the GIS map examples. Students were then encouraged to explain the following questions:

Q2: *Can you explain the process of GIS map creation from the result of your group discussion?* Each group then presented their own group discussion idea of the process of creating a GIS map. During the presentation of each group, other groups were able to ask any questions they had. All groups participated in the discussion, with all allowed to present and discuss until the last group.

Q3: *From all groups' presentations, can we determine which is the most appropriate process to create a GIS map? You have to support your determination with the basic GIS knowledge you studied before.* Students discussed determining the most appropriate process to create a GIS map, based on their basic GIS knowledge. The teacher acted as a consultant to the student group discussion. Through activities, students started to develop an interest in problems using their prior knowledge.

Exploration

Students determined the most appropriate process to create a GIS map and presented it. The teacher then encouraged them to design their study on freshwater mollusc diversity and distribution by using this question: Q4: *Now you have chosen the most appropriate process to create a GIS map, can you use it to design the study on freshwater mollusc diversity and distribution in freshwater reservoirs in our campus?*

Students were given time to discuss their study design. Students were also encouraged to plan the field study and data collection, and to present their study design before their field study. Student groups were then divided into smaller groups that consisted of three students each. Students in each group conducted their group field study by utilising the GIS process as their own study design at the freshwater reservoirs in the study areas as follows:

- *Data collection*: Natural freshwater reservoirs were randomly selected as sampling areas. The sampling points were decided in each sampling area. Each sampling point was decided in a 1 m^2 quadrant. The distance between each quadrant was about 25-30 m apart along the bank and transectional line. The collected molluscs were specified for geographical coordinates, counted and identified. Water pH, water temperature, dissolved oxygen (DO) and types of water plants were also recorded. The collected data were recorded in the database to use them in the GIS process;
- *Data to GIS*: data files were then organised into the GIS process. All files were saved as a table that consisted of sampling points coordinates, sampling date and time, number and species of molluscs from each quadrant of the sampling area. This table was then transferred to the GIS program to be the layer of the GIS. This layer was overlaid on the digital map of the study area. Thus, the GIS map consisted of two layers of presentation that was able to present all the sampling areas in the study area.

Through this activity, students had the opportunity to investigate the materials or data regarding the topic they were studying. If there were some students who had prior knowledge about the topic, the exploration time provided them with time to become familiar with materials and data.

Explanation

Each group calculated and presented the ecological values (Shannon-Weiner diversity index, species richness, and species evenness) for use in their interpretations. Students' calculated values are listed in Table 1.

Data from the GIS

The GIS map contained a study area digital map that was overlaid with all the sampling points shown as dots. Using *PC Arc View 3.2a* for GIS maps, each selected dot presents an identifiable results table that shows the numbers, types, shell size of molluscs, types of water plants, plus values for water pH, water temperature and DO of each sampling point, as shown in Figure 2. From the GIS map, students were able to see where their sampling points were located in the study area. They were also able to identify the environmental features around their sampling points, such as households, construction sites or other factors that might affect mollusc diversity and distribution.

Table 1: Students' calculated ecological values.

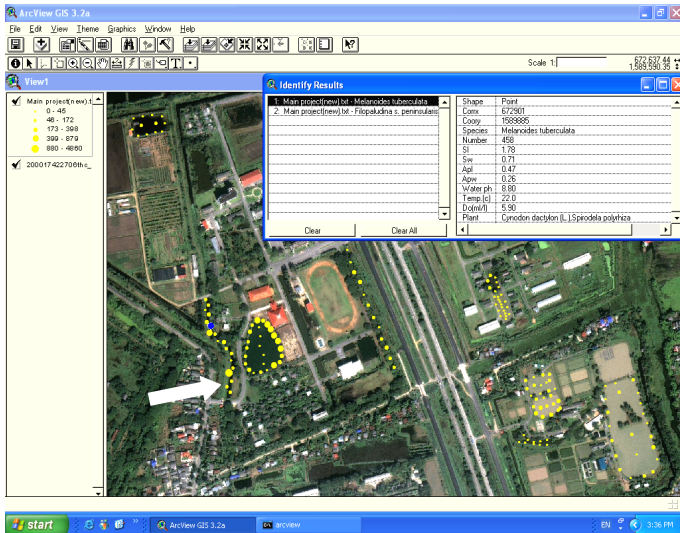| Pond	Diversity Index	Richness	Evenness
1	0.478	4	0.390
2	0.367	5	0.228
3	0.041	3	0.038
4	1.305	5	0.811
5	0.195	4	0.141
6	0.088	4	0.064
7	1.026	7	0.527
8	1.025	6	0.572
9	1.087	6	0.607
10	0.492	6	0.275
11	1.360	5	0.845

Figure 2: The GIS map showing all sampling points as dots (eg the dot at the arrow) in the study area. Data from each sampling point is shown as an identifiable tabled result (as in Table 1), where each dot was selected.

Students had the opportunity to explain the results of their exploration, and the teacher had opportunities to explain the scientific background of the topic. For example, students could be instructed on the interpretation of variance to mean ratio values and the Shannon-Wiener index values that were useful for their discussion and conclusion.

Elaboration

Students then summarised the analysis of the data that had been gathered. The teacher encouraged students to use their knowledge in order to explain more about the phenomena by using the following questions:

- Q_5: *Which pond is most diverse? You have to support your conclusions with your analysed data and data from the GIS.*
- Q_6: *Did any species dominate in either pond? If so, explain.*
- Q_7: *From your GIS data, do you think any environmental factor, such as household pollution, affected mollusc distribution and diversity?*
- Q_8: *What kind of distribution pattern of molluscs found in this study? Can you explain why molluscs had distribution pattern like this?*
- Q_9: *Were there opportunities for errors in your process or conclusion? If so, explain in detail.*

Students examined their analysed data and GIS data to answer the questions. They had to use various ways in order to find the answer. The GIS data were necessary – especially for Q_7. Using their analysed data and GIS data through the inquiry process, students were able to answer the questions. Therefore, their inquiry skills were improved.

Students also expanded their understanding about the topic through individual group activities and discussions. In addition, they participated in science process skill that leaded them to the understanding of the nature of science.

Evaluation

In the evaluation phase, students' answers, final project report and presentation were considered in the assessment. Students were assessed by both the teacher and through self-assessment. Students were then encouraged to solve a problem in the new situation by answering the following question: Q_{10}: *Can you create another project using GIS as a tool for your project? During the 5Es inquiry cycle, the concepts describing the nature of science were taught, insert in every step.*

Post-Test

Both the traditional and new instructional model groups were administered a post-test using the scientific literacy test in the dimension of understanding the nature of science so as to measure students' understanding of the nature of science. The post-test score of the traditional group and the new instructional model group were analysed utilising the analysis of covariance (ANCOVA) at the 0.05 significance level. The pre-test scores of both groups were used as the covariance for the data analysis.

RESULTS

The results from the ANCOVA statistical analyses for students from the traditional group and the new instructional model group in their understanding of the nature of science are presented in Figure 3.
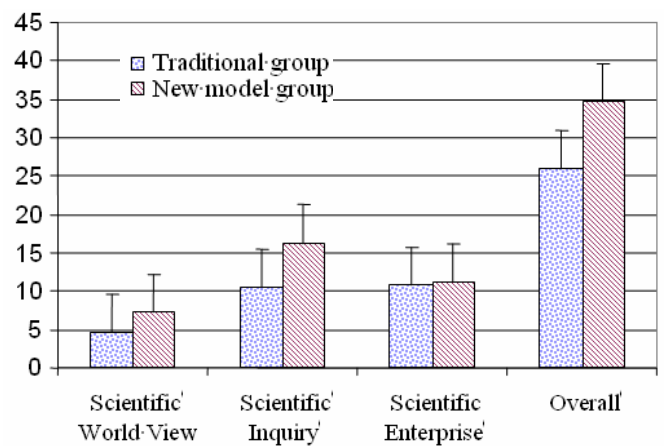

Figure 3: A comparison of students' scores concerning their understanding of the nature of science between the traditional and new instructional model groups.

The comparison between the traditional group and the new instructional model group focused on the post-test scores of their understanding of the nature of science. The new instructional model group average score was 34.67, whereas the traditional group averaged 25.93 (see Table 2).

Table 2: Means and standard deviations from the post-test.

Group	n	Mean	Standard Deviation
1.00	30	25.93	3.18
2.00	30	34.67	1.62
Total	60	30.30	5.07

Through an analysis of covariance, the post-test scores of both groups were compared; the results are shown in Tables 3 to 6.

Overall understanding of the nature of science post-test score is shown in Table 3, whereas Tables 4, 5 and 6 present the mean ($\overline{x}$), F-values and p-values of each part of the understanding of the nature of science scores concerning a scientific world view, scientific inquiry and scientific enterprise.

Table 3: ANCOVA results of the post-test scores on the understanding the nature of science (overall score).

Group	n	$\overline{X}$	SS	MS	F	P
1 [t]	30	25.93	49.79	49.79	20.44	0.00*
2 [n]	30	34.67				
Total	60	30.30				

t= traditional group;
n= new instructional model group;
* Significant difference at the 0.05 level.

Table 4: ANCOVA results of the post-test scores on the understanding of the nature of science concerning a scientific world view.

Group	n	$\overline{X}$	SS	MS	F	P
1 [t]	30	4.67	37.31	37.31	66.41	0.00*
2 [n]	30	7.20				
Total	60					

t= traditional group;
n= new instructional model group;
* Significant difference at the 0.05 level.

Table 5: ANCOVA results of the post-test scores on understanding of the nature of science regarding scientific inquiry.

Group	n	$\overline{X}$	SS	MS	F	P
1 [t]	30	10.57	42.69	42.69	32.68	0.00*
2 [n]	30	16.27				
Total	60	13.42				

t= traditional group;
n= new instructional model group;
* Significant difference at the 0.05 level.

Table 6: ANCOVA results of the post-test score on understanding the nature of science for scientific enterprise.

Group	n	$\overline{X}$	SS	MS	F	P
1 [t]	30	10.70	2.38	2.38	2.39	0.13[ns]
2 [n]	30	11.20				
Total	60	10.95				

t = traditional group;
n = new instructional model group;
ns = non-significant.

Concerning the new instructional model group, the overall score of the understanding of the nature of science was significantly higher than the traditional group at the 0.05 level (Table 3). Regarding students' understanding of the nature of science in the *scientific world view* and *scientific inquiry* scores, the new instructional model group scored significantly higher than the traditional group did at the 0.05 level (Tables 4 and 5, respectively). However, there was no significant difference detected in the scores between the traditional and new instructional model groups concerning the *scientific enterprise* aspect (Table 6).

DISCUSSION

The new instructional model facilitated enhanced scientific literacy in ecology students in the dimension of their understanding of the nature of science. The new instructional model can be utilised as a tool to help students to become fully scientifically literate persons. This study has shown that the new instructional model helped improve students' overall understanding of the nature of science.

However, it was also noticed that students enhanced their understanding of the nature of science only in two parts, specifically *scientific world view* and *scientific inquiry*. There was no significant difference found between the scores of the traditional group and the new instructional model group in the area of *scientific enterprise*. This may be because scientific enterprise focused on the awareness of the impact of science and technology on society, but students concentrated more in their problem solving activities than in developing awareness of social impact. Although both groups' average scores of scientific enterprise were higher than 10, the instructional model should add some activities that emphasise more on scientific enterprise.

There are various topics in science that are appropriate to construct an instructional model that can help students to enhance their scientific literacy levels. This study is an example of the use of the instructional model to enhance students' scientific literacy in the dimension other than content knowledge. There are several ways that a new instructional model can be modified or expanded so as to fit the aims of individual instructors.

Other instructional topics should be constructed to enhance students' scientific literacy in other dimensions. Students should learn not just a body of knowledge, but should also develop new ways of thinking and investigating, and should have an understanding of how science interacts with technology and society.

The new instructional model could be utilised as a tool to enhance students' scientific literacy along the dimension of understanding the nature of science in other instructional topics. Applying the new instructional model into an ecology class not only enhanced students' scientific literacy in the dimension of understanding of the nature of science, but also helped shy and quiet students to fit in with the rest of the students in the laboratory. These students showed that they conduct their best work in their groups and they studied together in order to solve various problems. These students also expressed that the ecology laboratory was more fun to engage in and that the ecological concepts made more sense. They enjoyed the laboratory and wanted to incorporate the new instructional model into other ecology laboratories.

CONCLUSIONS

Students' overall scores in their understanding of the nature of the science for the new instructional model group was significantly higher than for the traditionally taught group of students. Further, students in the new instructional model group also showed higher understanding of the nature of science with regard to *scientific world view* and *scientific inquiry*.

There was no significant difference detected with regard to the *scientific enterprise* scores between the traditional group and the new instructional model group. However, both groups' mean scores were higher than 10 out of 15. This shows that the use of new a instructional model that integrates GIS techniques and the 5Es inquiry cycle was able to enhance students' understanding of the nature of science.

Moreover, the results of the field study also helped students to specify the appropriate water reservoirs that they were able to sample molluscs from in the species that they wanted to study. The students involved also developed their inquiry learning skills, which would be very useful for their life-long learning skills in the future.

REFERENCES

1. Miller, J.D., The measurement of scientific literacy. *Public. Underst. Science,* **7**, 29-48(1998).
2. Lederman, N., Students' and teachers' conception of the nature of science: a review of research. *J. Res. Science Teaching*, **29**, 331-359 (1992).
3. Solomon, J., Duveen, J., Scot, L. and McCathy, S., Teaching about the nature of science through history: action research in classroom. *J. Res. Science Teaching*, **29**, 409-421 (1992).
4. Chiappetta, E.L. and Kobella, T.R., *Science Instruction in the Middle and Secondary Schools*. Upper Saddle River: Merrill/Prentice Hall (2002).
5. National Research Council (NRC), *National Science Education Standard*. Washington, D.C.: National Academic Press (1996).
6. Science For All Americans (SFAA), The Nature of Science, (2005), http://project2061.org/publication/sfaa/online/chapter1.htm
7. Catier, J.L., Passmore, C.M. and Stewart, J., Balancing generality and authenticity: framework for science inquiry in education. *Proc. 6th Inter. History, Philosophy and Science Teaching Meeting*, Denver, USA, 7-11 (2001).
8. National Academy of Science (NAS), *Inquiry and National Science Education Standard.* Washington, D.C.: National Academy Press (2000).
9. National Academy of Science (NAS), *Laboratory Experiences and Students' Learning*. In: NAS, America's Laboratory Report: Investigations in High School Science. Chapter 3, 1-20 (2005).
10. Elder, J.F. and Collins, J.J., Freshwater mollusks as indicators of biodiversity contamination. *Toxicology*, **122**, 37-74 (1991).
11. Macintosh, D.J., Ashton, E.C. and Havenson, S., Mangrove rehabilitation and intertidal biodiversity: a study in Ranong mangrove ecosystem, Thailand. *Estuar. Coastine Shelf. S.,* **55**, 331-345 (2002).
12. Ashton, E.C., Macintosh, D.J. and Hogarth. P.J., A baseline of diversity and community ecology of crab and molluskan macrofauna in the Sematan mangrove forest, Sarawak. *J. Trop. Ecology*, **19**, 127-142 (2003).
13. Johnson, C.A., *Geographic Information System in Ecology*. Minnesota: Blackwell Science (1988).
14. Laugksch, C.R. and Sparco, E.P., Construction of a paper and pencil test of basic scientific literacy based on selected literacy goals recommended by the American Association for the Advancement of Science. *Public. Underst. Science*, **5**, 331-359 (1996).
15. Brandt, R.A.M. The non-marine aquatic mollusea in Thailand. *Archiv für Molluskenkunde*, **105**,1-143 (1974).
16. Chitramvong, Y.P., The bithyniidae (*gastropoda prosobranchia*) of Thailand: comparative external morphology. *Malacol. Review*, **25**, 21-38 (1992).
17. Kaewjam, R.S. Guide for the identification of freshwater snails of the family pilidae in Thailand. *Walkerana*, **2**, 173-186(1987).
18. Upatham, E.S., Sornmanı, S., Kittikorn,V., Lohachit, C. and Burch, J.B., Identification key for fresh and brackish-water snail of Thailand. *Malacol. Review*, **25**, 21-38 (1983).