Implementing the Earth System Science Curriculum in School through Research-Based Learning and Technology Enhancing 21st Century Skills

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Abstract. According to IPST responsible for promoting the teaching of science from elementary to upper secondary schools in Thailand, IPST has developed Earth System Science curriculum since 2009 to raise understanding of the earth system, promote awareness of environmental problems, and increase 21st century skills in young generation. This study focused on implementing the ESS curriculum in schools to enhance 21st century skills and inspire students to become a young scientist based on research and technology. The process starts with recruit universities to be a partner, arrange a workshop, implement curriculum in school and finally, record student and teacher satisfaction by quantitative descriptive. After twelve years, the results show that, IPST and partners have implemented ESS curriculum in 896 participating schools of normal schools and enrichment science classroom schools all over the country. The schools integrated the curriculum as an additional subject, science subject, and science camps. ESS curriculum created research-based learning in STEM allowing students to employ their knowledge from various disciplines to conduct environmental research. Participants, including students and teachers had positive attitudes toward the curriculum, not only develop research skills, but also the 21st century skills, namely critical thinking, collaboration, communication, information literacy, technology literacy and social skills.

1. Introduction

The world in the 21st century is rapidly changing as innovations have been developed but serious environmental problems have also emerged and more complicated [1, 2]. It is important that students in this century develop the 21st century skills to handle such problems for better living [3] and prepare the essential skills including life skills for their future careers [4]. These skills are associated with deeper learning such as analytic reasoning, complex problem solving, communication and collaboration with other parties, information and technology literacy, responsibility, and global awareness for success in work and life [5, 6]. Consequently, The education need to prepare smarter citizens who curious, creative, solving complex problems, leading, perspective, flexible, communicative, collaborating and networking [7, 8, 9]. The Institute for the Promotion of Teaching Science and Technology (IPST) realizes the significance of such skills and in 2009 launched Earth System Science (ESS) curriculum that educate through research-based learning by collaborating with Global Learning and Observations to Benefit the Environment Program (The GLOBE Program) supported by National Aeronautics and Space Administration (NASA). The purposes of this research were (a) to implement ESS curriculum in
schools, (b) to encourage students to learn and understand the earth system and environmental problems through scientific process, (c) to promote student to practice and improve students’ research skills using standard scientific equipment for environmental observation as well as the 21st century skills, and (d) to inspire students to become a young scientist.

2. Earth System Science (ESS) curriculum
ESS curriculum is an integrative scientific discipline that involves the study of the relationships among earth components in the environment. Furthermore, understanding of the cycles of energy, water, and chemical elements and any changes in the near future that may affect the quality of life and well-being of organisms on earth [10]. The discipline allows students to learn and understand the earth system by using scientific process (Figure 1) and GLOBE Protocols. ESS curriculum encourage students to describe and predict possible environmental phenomena based on their observations under rapidly changing conditions.

ESS Learning Process will promote the new strategies of Environmental Science Learning in Thailand, not only read from the textbooks as well as traditional learning [10]. ESS curriculum encourage student’s learning by doing namely, explore and observe their local environment, ask research question, take the measurement, use the scientific equipment, analyze, interpret, and conclude the research project. This creative curriculum runs through research-based learning that align with the 21st century literacies. IPST has designed the curriculum by using GLOBE Protocols as a tool to observe and measure the environment. GLOBE Protocols are science protocols, which collect the environmental data and follow the phenomena of Atmosphere, Biosphere, Hydrosphere, Pedosphere, and Earth as a System [11]. The tool for learning GLOBE Protocols, start with simple and modern equipment to advance technology. For example, students observe the cloud type by the eye compares with the GLOBE cloud chart to follow the weather changing. Moreover, they can apply the mobile application to identify the cloud type promptly. An advance part, student use the satellite data from NASA satellite to interpret the weather situation.
ESS curriculum consists of student books and teacher’s guidebooks in Thai and English version for students in two levels: 4th to 6th and 7th to 9th grades (Figure 2) but it can apply to the other level as same as scientific process and protocols.

**Figure 2.** ESS Student Books and Teacher’s Guidebooks in Thai and English version.

3. **Methods**
The methods have designed to implement the ESS curriculum for student Grade 4-6 and 7-9 in four steps as follows (Figure 3):

![ESS Curriculum Implementation Model](image)

**Figure 3.** ESS Curriculum Implementation Model.
3.1. Step 1: University Recruitment
Since 2009, IPST has invited scientists from university in the Faculty of Science and science educators from the Faculty of Education to encourage and promote teaching and learning of earth system in schools. IPST has utilized ESS Curriculum and GLOBE Protocols as an instruction and tools for environmental learning with the scientific process.

3.2. Step 2: Train-The-Trainer (TTT) Workshop
IPST has designed Train-The-Trainer Workshop. All universities must be certified before implementing GLOBE Protocols and ESS Curriculum. TTT workshop took five days for the field activities and ESS learning Process that incorporated STEM education as well. Field activities included the use of basic materials, instruments, technology and mobile application in four spheres: Atmosphere, Hydrosphere, Pedosphere and Biosphere (Figure 4). The university then proposed a project to become ESS University. One project fund per one university.

![Figure 4. GLOBE Protocols activities. (a) Study site selection by drone, (b) Weather station, and (c) Study soil profile.](image)

3.3. Step 3: ESS Network Implementation
IPST implemented ESS curriculum in Grade 4-9 from participating schools and later expanded to enriched-science-classroom schools in Grade 8 all over the country. Participants registered for membership and were required to participate in ESS and GLOBE Protocols workshop organized by IPST and ESS University partners.

IPST has created an agenda, instructional media, and using GLOBE Protocols and basic equipment created by The GLOBE Program. All workshops followed this procedure. The ESS universities may use this protocol to train school or student in their local areas when interesting environmental problems were raised.

The ESS curriculum was suggested to use as an additional program for students who showed interest in science by integrating this curriculum in a normal classroom, special science classroom, environmental camp, and research camp.

3.4. Step 4: Achievement in School/Student and Teacher Satisfaction
IPST and university partners have supervised and encouraged students as mentors to develop environmental researches in their local communities. The number of participating school was recorded. Student researches were presented in schools, science fairs, and national conferences. Outstanding research was chosen to present their works internationally.

Evaluation ESS curriculum satisfaction by qualitative descriptive methods [3, 12, 13, 14] from 1,794 students and 296 teachers in 75 participating schools was conducted using interviews and self-reflection. Students and teachers were asked to write their opinions on their satisfaction and benefit of ESS in papers and shared them with the groups.
4. Result and Discussion

4.1. Implementation ESS curriculum in schools
Since the implementation in 2009 to 2020, IPST has arranged 26 workshops and funded 42 ESS university partners (Figure 5a and Appendix A) to conduct ESS curriculum in participating schools. There have been more than 896 schools employing the ESS curriculum in extra curriculum classrooms (Figure 5b). Many schools expressed their interest in applying ESS curriculum in their schools to improve students’ scientific and problem-solving skills through research-based learning. Nowadays, schools can apply ESS curriculum by themselves from online ESS educational resources to build student understanding of scientific protocols and STEM [15]. Besides implementation in schools, university partners also integrated the curriculum in science subject to pre-service teachers. Because of advantage of research-based learning approach in environmental education [16].

![Figure 5. (a) ESS University Partner and (b) Distribution of ESS School Network from 2009 – 2020](image)

4.2. Evaluation ESS curriculum achievement and satisfaction from Student and Teacher
The results from the interview showed that students and teachers had positive attitudes toward the curriculum (Appendix B). Students have learned many scientific skills to understand the connection of the earth system. Furthermore, they were able to perform field measurements by using GLOBE Protocols and scientific instruments, played the part of a young scientist, and developed new research ideas (Figure 6). Students combined diverse disciplines to form new research projects, which focused on the relationships of earth components and environmental problems in their local areas. To accomplish a research goal, they required collaboration and communication among students, teachers, scientists, and communities. According to GLOBE Protocols that supported by NASA, students get advantageous to use a modern technology for their learning, such as a simple mobile application to measure the environment, satellite image, and satellite data. The preferential opportunity meets NASA scientists for inspiration and interchange knowledge about the real environmental situation.
The example of student research [17] was “The Study of Relation between Sky Color and the Amount of PM10 and PM2.5 at Muang Chiang Mai, Chiang Mai Province”. The research began with students’ questions about the aerosol problem in Chiang Mai over the Criteria for the Air Quality Index of Thailand and affected human health in winter season every year. In addition, the problem affected visibility of Doi Suthep, which is the famous place for tourist. Students have designed the methodology to measure the amount of aerosol by observing the sky color and using technology. Consequently, this research has shown student’s learning process from explore and observe the local environment, curious, and investigate the solution. The solution was simple and benefit to their community.

From inquiry learning activities, doing a research project [3] and applying technology [18] had an effective impact on learning. Students have increased scientific thinking, critical thinking skill and problem solving skill by developing the potential to solve problems, interpreting information, conducting conclusions [6, 19], and improving their own knowledge along the process [13, 14, 20]. Technology combination into the curriculum powerfully assists the success of literacy skills; information, media, and technology literacy [21]. Learning environment through the GLOBE mobile application was promoting a great learning experience for students by communicating with system dynamically devices from anywhere and anytime [22]. All of these skills emphasize students to enhance thinking systematically process and other abilities [1]. The evidences of developing critical thinking skills across research-based learning can prove by the students were able to construct the knowledge by observe, explain, analyze, interpret, evaluate, summarize the data [7, 12, 14], and develop the research report of their own that was a significant evidence.

Furthermore, students were able to present and share their research publicly at an annual national conference – GLOBE Student Research Competition (GLOBE SRC). The outstanding researches have chosen to present and international conferences such as GLOBE Asia-Pacific Student Research Exchange, GLOBE International Virtual Science Symposium (GLOBE IVSS), and GLOBE Annual Conference, which have supported by IPST and NASA. Students have integrated the other language to communicate with foreign friends and scientists that encourage the communication skill [20, 23].
Therefore, Students who participated in ESS curriculum have acquired an understanding of the earth system and environmental problem solving in their local areas through research process and technology. They have improved a deeper understanding of research skills [24, 25], increased many skills of technology, and life skills as well as 21st century skills [26, 27] (Table 1).

Table 1. Conformity of Earth System Science Learning Process to 21st Century Skills

| 21st Century Skills | Step 1^a | Step 2^b | Step 3^c | Step 4^d | Step 5^e | Step 6^f | Step 7^g |
|---------------------|----------|----------|----------|----------|----------|----------|----------|
| Learning skills     |          |          |          |          |          |          |          |
| Critical thinking   | •        | •        | •        | •        | •        |          |          |
| Creativity          | •        | •        | •        |          |          |          |          |
| Collaboration       |          |          |          |          |          |          |          |
| Communication       |          |          |          |          |          |          |          |
| Literacy skills     |          |          |          |          |          |          |          |
| Information literacy| •        |          |          |          |          |          |          |
| Media literacy      | •        |          |          |          |          |          |          |
| Technology literacy | •        |          |          |          |          |          |          |
| Life skills         |          |          |          |          |          |          |          |
| Flexibility         |          |          |          |          |          |          | •        |
| Leadership          |          |          |          |          |          |          | •        |
| Initiative          |          |          |          |          |          |          | •        |
| Productivity        |          |          |          |          |          |          | •        |
| Social skills       |          |          |          |          |          |          | •        |

^a Step 1: Explore and observe the environment  
^b Step 2: Generate and analyze research question  
^c Step 3: Search, plan and define the proposal  
^d Step 4: Measure and collect data  
^e Step 5: Analyze and interpret data  
^f Step 6: Conclude and discuss data  
^g Step 7: Write and present the research report

For teacher satisfaction, they reflected that ESS activity integrated several disciplines to create new cognitive. The activities encouraged students to think critically about problem solving, enhancing students’ positive scientific attitude and environmental awareness. Research activities truly produced young scientists at least established science and environmental awareness to young people. The learning in nature is an integrative learning because students have combined several knowledge that corresponding to their topic while undergoing the research project [9]. Moreover, many essential skills have increased, in particular critical thinking, technical skills, collaboration, communication, research and social skills also known as 21st century skills.

Although students’ learning was practical and beneficial, implement curriculum in school has some the barriers. There were school period, nature study site, and changing school policy. Therefore, IPST has determined the ESS curriculum into students Grade 8th of enriched-science-classroom schools, together with promoted and supported in normal schools over the country to help students improve 21st century skills.

5. Conclusion

ESS curriculum brings together the research process, knowledge and technology from the several disciplines of earth science to understand the earth system. Moreover, knowing the nature aligns science can predict the environmental impacts from climate change, disasters, and other issues. The curriculum has been employed in 896 participating schools of normal schools and enrichment science classroom schools for over a decade and its outputs are exceptionally beneficial to the communities. The answers from the interview 75 schools display that students and teachers was appreciate upon the curriculum. Students have shown an evidence to understand the earth system and strengthen 12 abilities of 21st
century skills by performing real science in a natural setting, training to use scientific instruments, and practice scientific methods. Additionally, they can generate and analyze research questions from observations, investigate, analyze, and answer their questions through experiments and inquiries. Finally, they have presented and shared their research to society. Accordingly, research-based learning will support lifelong learning in students [20, 23] by doing in real-life while operating their own research [28].

Not only have students improved their skills, teachers also have presented positive attitudes toward the curriculum. They have accumulated their new teaching strategies in the classrooms and acquired new knowledge from students’ researches as they serve as supporters, facilitators and advisors. In addition, they play as a part of the coordinator, partner, administrator, team builder, and co-learner with students learning environment and construct the new cognitive by themselves [9]. The other advantage of the curriculum for teacher, this year 2020, IPST has awarded GLOBE Teacher Shining Star: ESS Curriculum Implementation in School to admiring teachers who have contributed the curriculum to students continuously. However, the repeated conduct research-based learning to students was laborious for a teacher, but it will enhance 21st century skills of a student’s mind eventually.

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Appendices
Appendix A: ESS University Network 2009-2020
1. Burapha University
2. Chiang Mai Rajabhat University
3. Chiang Mai University
4. Chiang Rai Rajabhat University
5. Kanchanaburi Rajabhat University
6. Kasetsart University Kamphaeng Saen Campus
7. Khon Kaen University
8. Khon Kaen University, Nong Khai Campus
9. King Mongkut's Institute of Technology Thonburi
10. King Mongkut's Institute of Technology Thonburi
11. Lampang Rajabhat University
12. Loei Rajabhat University
13. Mae Fah Luang University
14. Maejo University
15. Mahasarakham University
16. Mahidol University
17. Nakorn Pathom Rajabhat University
18. Nakorn Ratchasima Rajabhat University
19. Nakhon Si Thammarat Rajabhat University
20. Naresuan University
21. Phranakhon Si Ayutthaya Rajabhat University
22. Phetchabun Rajabhat University
23. Phetchaburi Rajabhat University
24. Phuket Rajabhat University
25. Pibulsongkram Rajabhat University
26. Prince of Songkla University Surat Thani Campus
27. Rajabhat Rajanagarindra University
28. Rajabhat Rambhai Barni University
29. Rajamangala University of Technology Isan
30. Rajamangala University of Technology Suvarnabhumi
31. Silpakorn University
32. Sirindhorn International Institute of Technology
33. Srinakharinwirot University
34. Suranaree University of Technology
35. Suratthani Rajabhat University
36. Surindra Rajabhat University
37. Thaksin University, Phattalung Campus
38. Ubon Ratchathani University
39. Ubon Ratchathani Rajabhat University
40. Udon Thani Rajabhat University
41. Uttaradit Rajabhat University
42. Walailak University

Appendix B: Student and Teacher Interviews and Self-Reflection

Major issue of student and teacher interviews and self-reflection as follows;
1. The Student has fun doing and learning new things.
2. The Student has happy that they participate in the activity.
3. The Student has a chance to conduct scientific experiments that help me remember scientific contents better.
4. The Student has understood the earth system with the connection of science and mathematics.
5. The Student has practiced to create a question and develop research questions.
6. The Student has learned and understand their local environment.
7. The Student has an experience about how to use scientific instrument.
8. The Student has performed field measurements.
9. The Student has increased expertise for doing the research.
10. The Student has learned many scientific skills in collecting data, data preparation and other details.
11. ESS activity was to enhance the scientific attitude by understand the earth system through the scientific process.
12. ESS activity encourages critical thinking about problem solving.
13. ESS activity ingrates several knowledge to solve the environmental problem.
14. Team building is the one advantage of the activity.
15. ESS activity has created a young scientist with environmental mind.
16. Continuously proceed ESS activity will increase environmental awareness in student’s mind.

1 Data from Thaksin University Phattalung Campus, Srinakharinwirot University, Udon Thani Rajabhat University, Ubon Ratchathani University, Surindra Rajabhat University, and Phetchabun Rajabhat University

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