

Learning Science from Toys: A Pathway to Successful Integrated STEM Teaching and Learning in Thai Middle School

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Author note: 1. The survey research on the use of "Science of Toys" textbook was carried out by a team of science educators and staff in the Secondary Science Department, IPST, during the years 2012 – 2013. The author is one of the three main investigators. 2. Articles with the same title, but partially different content, are in the process of publication in the Proceedings of ISMTEC 2014 and ISET 2014.

Abstract

A textbook, *Science of Toys*, developed by the Secondary Science Department of the Institute for the Promotion of Teaching Science and Technology (IPST), is designed to be used in an elective course of the Thai middle school science curriculum. The book contains lessons and learning activities that offer students opportunities to learn science in an integrated approach; that is, students learn scientific concepts and principles such as center of gravity, electronics and simple machines through inquiring and designing, building, testing and playing with toys. An investigation on opinions and suggestions from teachers and students who have used a trial version of the book was undertaken. Three teachers and a total of 124 students from Grade 7 to Grade 9 participated. Data were collected through interviews, questionnaires and classroom observations. The results show that all students and teachers were very satisfied with the content, learning activities and integrated approach of the book. Because of the comparable features between the approach in the textbook and the STEM Guiding Principles (Vasquez, Sneider and Comer, 2013), the results suggest that the approach of teaching science through toys as described in the textbook could have promising implications on teaching and learning integrated STEM in Thai middle school. To be more conclusive on the implications, further investigations are needed to answer several questions; for example, Would STEM literacy and learning achievement of students improve after learning integrated STEM under the approach? Which level of integration (Vasquez et al., 2013) gives the best results? Could the same approach be applied to teach mathematics? Much more data from teachers and students from all types of schools are also needed.

Keywords: Integrated STEM teaching and learning, STEM Guiding Principles.

1. Introduction

1.1 Science of Toys Textbook

In order to provide a high quality learning material for Thai teachers who teach elective courses in the Thai middle school science curriculum, the Secondary Science Department of the Institute for the Promotion of Teaching Science and Technology (IPST) has developed a set of textbooks for a 40-hour, single-unit elective course. The set includes five textbooks focusing on five different topics: Renewable Energy, Energy for Transportation, Science of Beauty and Cosmetics, Fun Science Projects and Science of Toys. Among the five books, *The Science of Toys* (IPST, 2013a) is the most widely used; since its first edition became available in June 2013, all of the 30,000 copies were sold out in six months. *Science of Toys* textbook has four chapters: 1) Science and Toys; 2) Simple

Machines and Toys; 3) Electric Circuit, Electronics and Toys; and 4) Let's Make Toys. Learning science from toys by following the approach of *Science of Toys* textbook could be considered an integrated approach because the book implicitly integrates science, technology, engineering and mathematics or the “STEM” disciplines in its content and learning activities. Therefore, the results from a survey that collects feedback from students and teachers who have used the trial version of the book in their classes could be valuable not only to the book development, but also to the ongoing effort to promote integrated STEM teaching and learning in Thai middle schools (IPST, 2013b).



Figure 1: Covers of *Science of Toys* textbook (left) and its *Teacher's Guide* (right).



Figure 2: Toys in *Science of Toys* textbook developed by the Secondary Science Department, IPST.

1.2 Integrated STEM Teaching and Learning

Integrated STEM teaching and learning, or STEM education, is an interdisciplinary approach to teaching and learning that removes the traditional barriers separating the four disciplines of science, technology, engineering, and mathematics and integrates them into real-world, rigorous, and relevant learning experiences for students (Vasquez et al., 2013). STEM education in itself is not a curriculum, but a way of organizing and delivering instruction (Vasquez et al., 2013). By integrating technology and engineering into science and mathematics, there are many benefits that could improve the current situation in Thailand's science and mathematics education. For example, there are studies showing that learning science through engineering design-based approaches could result in significant

learning gains in science content such as physics (Fortus, Dershimer, Krajcik, Marx, & Mamlok-Naaman, 2004; Svarovsky & Shaffer, 2007; Wendell & Lee, 2010), chemistry (Apedoe, Reynolds, Ellefson, & Schunn, 2008) and environmental science (Riskowski, Todd, Wee, Dark & Harbor, 2009). Also, some studies have shown that students who learn scientific concepts through authentic engineering design approaches attained significantly higher achievement, more engaging experience and higher knowledge retention than those who learn through scripted inquiry-based teaching methods, especially for students who are underrepresented groups such as Black and Hispanic as well as those with special needs (Mehalik, Doppelt, & Schunn, 2008; Cantrell, Pekcan, Itani, & Velasquez-Bryant, 2006). According to Vasquez, Sneider and Comer (2013), there are four levels of integration: disciplinary, multidisciplinary, interdisciplinary and transdisciplinary. The descriptions of each level are shown in Figure 3.

In 2013, integrated STEM was brought to the attention of academic staff of IPST, the national institute responsible for developing science, mathematics and technology standards, curricula, learning material and assessment for Thai K-12 education. After some discussions, seminars, workshops and experimental activities, the IPST executive committee decided to initiate a campaign to promote integrated STEM teaching and learning in Thai K-12 schools under “the Development and Promotion of STEM Education Project” (IPST, 2013b). In the early phase of the project, there could be many unforeseen challenges facing educators and teachers who are involved. It was thought that the investigation of the opinions and suggestions from the students and teachers who have used *Science of Toys* textbook might reveal some implications that could lead to one of many effective approaches in implementation of the integrated STEM strategies in Thai middle schools.

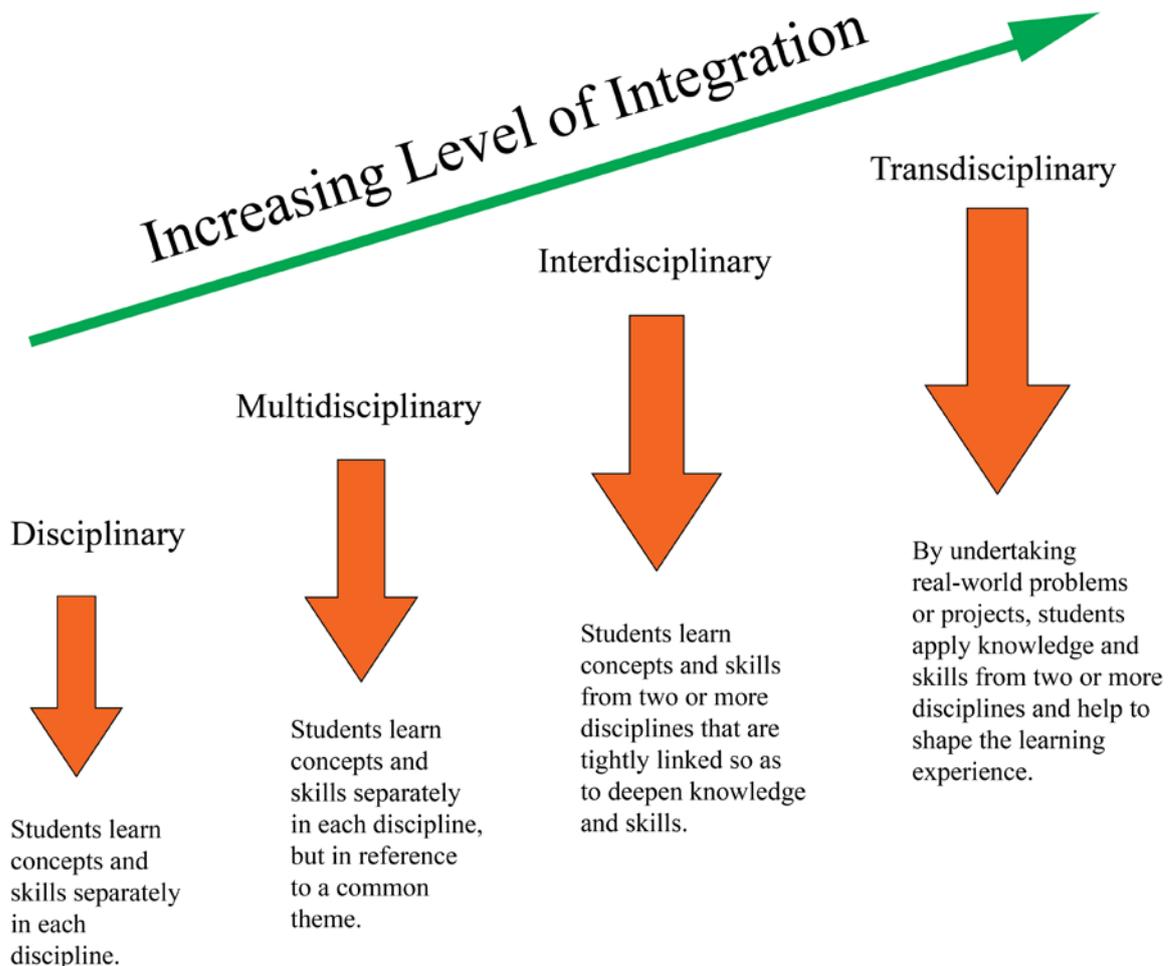


Figure 3: A continuum of STEM approaches to curriculum integration (Vasquez et al., 2013).

2. Research Objectives

The investigation involves survey research that aims to explore, collect and analyze opinions and suggestions from students and teachers who have used a trial version of *Science of Toys* textbook. There are three aspects of the book that the investigation focuses on: (1) Content, (2) Learning activities, and (3) Teaching approach.

3. Methodology

3.1 Method

Items for classroom observations, questionnaires and interviews were developed by the researchers based on their knowledge and experience from previous investigations on other textbooks. The items were later reviewed and validated by experienced teachers and university professors before being adopted as research instruments. Most of the questions in the interviews and questionnaires ask for levels of agreement regarding statements about the book's content, learning activities and teaching approach. There are four levels of agreement: Strongly agree, Agree, Somewhat agree and Disagree. Moreover, there are questions that ask for any suggestions that the students and teachers might have.

3.2 Data Collection

The surveys were conducted late into the second semester of academic year 2013. The researchers first communicated with the teachers who had agreed to use the trial version of the book in their classes for one semester. The teachers were informed about the survey procedures and the research instruments. Then, the researchers made an appointment with each of the teachers to visit the schools. During the visit, the researchers conducted classroom observations and interviews with the students and the teachers. At the end of each visit, the researchers handed out questionnaires to the teachers for distribution to the students. The teachers were given standard procedures for administering the questionnaires to the students. In the questionnaires, students were asked to provide information on their grade level and the elective courses that they took while in middle school. The students were assured of their anonymity to avoid social pressure and to encourage honesty in responding to the questions. Completed questionnaires were collected by the teachers and mailed back to the researchers about a week later.

3.3 Participants

The teachers who participated in the survey research were selected based on their agreement to cooperate and their involvement in the development of the textbook. They were three female teachers who were teaching in three large-size schools in three different regions of Thailand – North, Northeast and Central. The teaching experiences of the teachers were 15, 17 and 20 years, respectively. The students who participated in the investigation were 34 students from Grade 7, 44 students from Grade 8 and 46 students from Grade 9. Students from Grade 9 were in an all-female class. Not all of the students were involved in the process of the textbook development.

3.4 Data Analysis

The responses from questionnaires and interview were grouped into three categories: (1) Content, (2) Learning activities and (3) Teaching approach.

(1) Content:

Students: We looked for students' level of agreement on three components: the scientific content, the questions at the end of each chapter and the graphic design. The highest level of agreement on the content corresponds to students

being able to understand the scientific concepts offered in the book, being motivated and able to gain better understanding by the questions in the book and being very satisfied with the book's graphic design. The lowest level on the content corresponds to students being unable to understand the scientific concepts, being unmotivated or unable to gain better understanding from questions in the book and being dissatisfied with the book's graphic design.

Teachers: We looked for teachers' level of agreement on three components: grade-level-appropriate content, usefulness in students' everyday lives and the clarity and comprehensibility of the explanations on scientific concepts.

(2) Learning activities:

Students: We looked for students' engagement in the learning activities, their accomplishments in designing and building toys and their willingness to talk about science in toys with others after completing the lessons. The highest level of agreement on the learning activities of the book corresponds to students being very engaged in the learning activities, being able to accomplish the design and construction of toys based on the science discussed in the book and being willing to talk about science in toys with others outside the classroom. The lowest level of agreement on the learning activities corresponds to students being dissatisfied with the learning activities, being unable to accomplish the design and construction of toys and being unwilling to talk about science in toys with others outside classroom.

Teachers: We looked for teachers' level of agreement on whether or not the activities could help develop students' skills in designing and building toys and the 4Cs skills in Learning and Innovation of the 21st Century Skills (Partnership for 21st Century Skills, 2009): critical thinking skills, communication skills, collaboration skills and creativity.

(3) Teaching approach:

Students: We looked for students' understandings of the learning objectives for each lesson and their satisfaction level with the approach of learning science through designing, building and playing with toys. The highest level of agreement with the teaching approach corresponds to students being able to understand the objectives of each lesson in the book and being very satisfied with the approach in learning science through designing, building and playing with toys. The lowest level of agreement with the teaching approach corresponds to students being unable to understand the objectives of each lesson in the book and being dissatisfied to learn science through designing, building and playing with toys.

Teachers: We looked for teachers' level of agreement on whether or not the instructional approach of the book could help develop students' reasoning skill and skill in designing and building toys.

Responses on level of agreement were assigned numerical values from 0 to 3, where 3 is for strongly agree, 2 for agree, 1 for somewhat agree and 0 for disagree. The mean values and standard deviations of each question item were obtained using basic statistics.

The interpretation of the mean values is the following:

- If the mean value is between 2.51 and 3.00) $2.51 \leq \bar{X} \leq 3.00$, students and teachers strongly agree with the item.
- If the mean value is between 1.51 and 2.50) $1.51 \leq \bar{X} \leq 2.50$, students and teachers agree with the item.
- If the mean value is between 1.00 and 1.50) $1.00 \leq \bar{X} \leq 1.50$, students and teachers somewhat agree with the item.
- If the mean value is between 0.00 and 0.99) $0.00 \leq \bar{X} \leq 0.99$, students and teachers disagree with the item.

Responses from the interviews and information on classroom observations were explored to seek relationships with the responses in the questionnaires. The information being collected in the classroom observations was the teacher's teaching approach and student's learning approach. Some examples of items in teacher's teaching approach are: teacher uses questions in the teacher's guide, teacher checks for students' prior understanding at the beginning of each unit, teacher summarizes main ideas at the end of each unit, and teacher extends the concepts being learned to its application in new and real-world situation. Some examples of items in student's learning approach are: students assign roles to each member in their groups, students work as a team in solving problems, students can finish the activities in time, students are engaged in activities, and students incorporate scientific reasoning in discussing and presenting their work.

Other suggestions and comments regarding the content, learning activities, teaching approach and any other issues were examined for validity and similarity by the researchers. Valid suggestions and comments were those being relevant and possible in the textbook development process. Similar suggestions and comments were those with the same or close in meaning but varied in uses of words or forms of sentences. They were counted for the number of times they were mentioned and then the numbers were converted into a percentage with respect to the total number of all the participating students.

4. Results and Discussion

The results can be divided into two categories: opinions and suggestions from students and opinions and suggestions from teachers. Each category consists of three components: (1) Content, (2) Learning activities and (3) Teaching approach.

Opinions and Suggestions from Students:

- (1) Content: The mean values for the level of agreement on whether or not the students were able to understand the scientific concepts and able to gain better understanding from the questions in the book are 2.75 and 2.61, respectively. The mean value for the level of agreement on whether or not the students were motivated by the question in the book and satisfied with the graphic design are both 2.31.
- (2) Learning activities: The mean values for the level of agreement on whether or not the students were engaged in the learning activities and whether or not they were able to accomplish the design and construction of toys based on the science discussed in the book are 2.73 and 2.61, respectively. The mean value for the level of agreement on whether or not the students were willing to talk about the science of toys with others outside classroom is 2.50.
- (3) Teaching approach: The mean values for the level of agreement on whether or not the students were able to understand the objectives of each lesson in the book and whether or not they were satisfied with learning science through designing, building and playing with toys are 2.54 and 2.68, respectively.

Opinions and Suggestions from Teachers:

- (1) Content: The mean value for the level of agreement on the usefulness of the content is 3.00 while the mean values for the level of agreement on the grade-level appropriateness and the clarity and comprehensibility of the explanations of the scientific concepts are both 2.33.
- (2) Learning activities: The mean value for the level of agreement on whether or not the activities could help develop 4Cs skills is 3.00 while the mean value for the level of agreement on whether or not the activities could develop skill in designing and building toys is 2.33
- (3) Teaching approach: The mean value for the level of agreement on whether or not the instructional approach of the book could support the development of students' reasoning skill is 3.00 while the mean value for the level of agreement on whether or not the approach could develop skill in designing and building toys is 2.67.

Qualitative data taken from responses in interviews and classroom observations were in agreement with the quantitative results.

Overall, the results indicate that the students and teachers were satisfied with the book's content, learning activities and the teaching approach because the mean values of all the items were between 1.51 and 3.00 which could be interpreted as either "Agree" ($1.51 \leq \bar{X} \leq 2.50$) or "Strongly Agree" ($2.51 \leq \bar{X} \leq 3.00$).

Furthermore, because of the design-based instruction and activities of *Science of Toys* textbook, we propose to make a comparison between the features of the textbook and the integrated STEM Guiding Principles (Vasquez et al., 2013). By doing so, we hope to find some implications on the strategies that could lead to successful implementation of integrated STEM teaching and learning in Thai middle schools.

According to Vasquez, Sneider and Comer (2013), the five STEM Guiding Principles for creating integrated STEM units are:

- (1) Focus on Integration: Combine two or more disciplines.
- (2) Establish Relevance: Make the activities relevant to students' lives and future careers.
- (3) Emphasize 21st Century Skills: Promote the development of desirable attributes of 21st Century workers, which are critical thinking, creativity, communication and collaboration.
- (4) Challenge the Students: Use grade-level-appropriate challenges to intrigue the students to want to learn.
- (5) Mix it up: Provide a variety of outcomes with some evaluations being designed by the students.

In *Science of Toys* textbooks, the features that correspond to each of the STEM Guiding Principles, in respective order, are:

- (1) Implicit Integration of Science, Mathematics and Engineering: In *Science of Toys* textbook, students learn scientific concepts through designing, building and playing with toys. They also have to use mathematical calculations to find some quantities involved in designing toys such as weight of an object, mechanical advantage of simple machines, voltage and electric current in a circuit, etc.
- (2) Relevance and Applicability: Toys are a part of everyone's childhood, and often as adults. Designing, making and repairing toys could help save the cost of purchasing or repairing toys. The skills can also be transferred to other objects in

- everyday life such as repairing home utilities that have simple mechanical or electrical components such as a fan, a swivel chair, bicycle or a lamp.
- (3) Development of 21st Century Skills: Most learning activities in the book ask students to discuss ideas in groups, to apply scientific concepts in designing and building toys and to present their work. In the process of working in groups, students' collaboration skill is developed. Their critical thinking skill is developed when they have to discuss, negotiate, analyze problems and defend their ideas and their work. In the process of designing and building toys, there could be many unforeseen problems; through this, students' problem-solving skills are developed. Regarding the development of students' creativity, students have to employ their creativity in designing toys, planning for their presentations and solving problems. Their communication skills are also developed through their discussions and presentations.
 - (4) Grade-Level-Appropriate Challenges: The content and activities in *Science of Toys* textbook were designed based on middle school-level learning indicators of the Basic Education Core Curriculum B.E. 2551 (A.D. 2008).
 - (5) Variety of Assessments: In each of the learning activities in *Science of Toys* textbook, students are assessed based on their group participation, their presentations and the toys that they have designed. They also have an opportunity to design their own toys and to create their own evaluation criteria.

From the discussion above, we see that the features in *Science of Toys* textbook are comparable to the features of the STEM Guiding Principles. Therefore, the results from our investigation could have implications for possible approaches in implementing integrated STEM in Thai middle schools. Some of the implications are:

- (1) Teach Integrated STEM in an Elective Course: *Science of Toys* textbook is designed for an elective course of the Thai middle school science curriculum. The results from the survey show that the students and teachers who have used the book for a one-semester course have had no difficulties in finding a time slot in their tight school schedule. Therefore, if integrated STEM is to be implemented in the Thai middle schools, it could be put in the elective course time slot, which would not interfere with the teaching and learning time of any core subjects.
- (2) Integrate in Interdisciplinary Level: The teaching approach of *Science of Toys* textbook allows students to learn about scientific concepts and relevant mathematics before the application of those concepts in designing and building toys. According to Vasquez, Sneider and Comer (2013), this is considered an interdisciplinary level of integration. The results from the survey show that the students and teachers were satisfied with the approach. They also agreed that this approach helps students understand scientific concepts and improve their designing and building skills.
- (3) Place Science as the dominant subject: *Science of Toys* textbook places science as the dominant subject in its integration with mathematics and engineering. Most of the students who have used the book strongly agree that they understand the concepts and are satisfied with the content. Hence, the implementation of integrated STEM in Thai middle schools might also consider placing science as the dominant subject in its integration.
- (4) Integrate under the Theme of Toys: *Science of Toys* textbook has shown to be very popular. All of its 30,000 copies of the first edition were sold out within six months after it was first available in bookstores. The result from our survey also shows that students strongly agree that they are engaged in the process of learning science from designing and building toys. Therefore, if the integrated

STEM teaching and learning is to be implemented in Thai middle schools, it might consider the integration under the theme of toys.

However, these implications would be more conclusive if further investigations are carried out to answer several questions; for example, Would STEM literacy and learning achievement of students improve after learning integrated STEM with the approach? Which level of integration gives the best results? Could the same approach be applied to teach mathematics? Much more data from teachers and students from all types of schools are also needed.

5. Conclusions and Implications for Integrated STEM Teaching and Learning

Students and teachers who had used the trial versions of *Science of Toys* textbook were satisfied with the content, learning activities and teaching approach of the book. All students strongly agreed that learning science through toys were engaging and helped them understand scientific concepts. All teachers agreed that the book helps students develop 21st Century Skills (Partnership for 21st Century Skills, 2009) and their skills in designing and making toys.

Because of the integrated features and the design-based activities of the book, the results from this investigation could have implications for integrated STEM implementation in Thai middle schools. However, to be more conclusive on the implications, further investigations are needed to answer several questions; for example, Would STEM literacy and learning achievement of students improve after learning integrated STEM with the approach? Which level of integration gives the best results? Could the same approach be applied to teach mathematics? Much more data from teachers and students from all types of schools are also needed.



After years of graduate study and research in particle physics, Raksapol Thananuwong joined the Institute for the Promotion of Teaching Science and Technology (IPST) in 2009. He initially worked as supporting academic staff in various projects, e.g. International Mathematics and Science Olympiad; TV science game show Wittaya-Supprayut; Science and Technology Conference for Youth, etc. After gaining more experience and training in science education, he joined teams of IPST science educators and teachers to design, develop and carry out research on preK-12 science learning materials, curriculum and assessment. Raksapol has written more than ten articles (mostly in Thai language) on science and science education and has conducted several workshops, seminars and activities on STEM teaching and learning for Thai teachers and students around the country. Raksapol earned bachelor's degree in physics from the University of Chicago, IL, USA, and master's degree in particle physics from Chulalongkorn University, Thailand. He has spent 18 months as a research assistant at the European Organization for Nuclear Research (CERN) in Geneva, Switzerland.

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