The Effect of Integrated Learning in Mathematics and Science on Student's Critical Thinking and Collaboration Skills

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Abstract: *Suan Sunandha Rajabhat University has offered Master of Arts Program in Mathematics Education and Master of Education Program in Science Education. The purpose of this study was to illustrate the use of integrated learning strategies to implement integrated mathematics and science education in reforming teaching profession. The subjects of this study were six graduate student teachers under the Project for the Promotion of Science and Mathematics Talented Teachers (PSMT), studying "Philosophy and Curriculum Development for Teachers" course. The teaching method was integrated learning strategies in mathematics and science education through model IDAC (**I**nvestigation, **D**iscussion, **A**nalysis, and **C**onclusion). The effect of developing integrated learning activity to do the experiments in comparing the elasticity of two different materials can increase students' experiences through a range of investigations (I) and discussions (D). The students obtained enough statistical power to analyze (A) and made reliable conclusion (C) to describe the definitions of 'Tensile Stress-Strain Properties in Materials'. Overall, students achieved the task and gained behavioral indicators at 'good level' towards the integration of mathematics and science to support 'critical thinking and collaboration skills'.*

Introduction

Since the results of achievement from PISA (Programme for International Student Assessment) in grade 8 students (15-year-olds) has shown that Thai students' average score below the OECD average score at different levels. In PISA 2012, Thailand were ranked in the 50thwith average score in mathematics 427 (OECD average 494) and ranked in the 48th with average score in science 444 (OECD average 501). Additionally, Thai students' proficiency level in mathematics literacy were at Level 2 about 27.3 % (lower score limit 420.1) and below Level 2 about 49.7 % and proficiency level in science literacy were at Level 2 about 37.5 % (lower score limit 409.5) and below Level 2 about 33.6 [1].These results showed that Thai student's knowledge and proficiency to do mathematics and science is critical for their future success in globally competitive age.

Most of Thai teachers use the traditional teaching strategies to control the learning environment and play the role of instructor and decision maker in regards to curriculum content and specific learning outcomes. They regard students as having 'knowledge holes' that need to be filled with information. In short, the teacher views that it is the teacher that causes learning to occur [2]. Too often mathematics education fails to engage student interests and is separate from their everyday experiences. However, research tells us that students learn best when encouraged to construct their own knowledge of the world around them [3].To improve the students' mathematics and science literacy, mathematics and science teachers should have the freedom to develop strategies that provide students with the opportunity to construct new knowledge and problem-solving skills through the process of defining and optimizing a solution for a real-world authentic problem. Likewise, science teachers should be able to connect the mathematics links to their subject area. Effective use of mathematics in science will strengthen each discipline. Research indicates that using integrated learning provides opportunities for more relevant and more stimulating experiences for learners [4].

Integrated Learning in Mathematics and Science

The idea to integrate mathematics and science deal with the extent to which teachers use examples, data, and information from a variety of disciplines and cultures to illustrate the key concepts, principles, generalizations, and theories in their subject area or discipline [5].There are different approaches of integration can be used in mathematics and science curriculum such as discipline specific, content, and process skills [6].

Discipline specific Integration

The discipline specific integration involves the integration of two or more different branches of mathematics or science. For example, discipline specific integration might include content and process skills in algebra (mathematical modeling) and geometry in mathematics and science contexts in physics, chemistry, and biology.

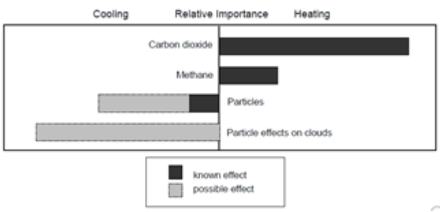
Examples from PISA 2012 that integrate mathematics involve the context of science in 'Sailing Ships' problem as the following [7]:

> *Ninety-five percent of world trade is moved by sea, by roughly 50,000 tankers, bulk carriers and container ships. Most of these ships use diesel fuel.*
>
> *Engineers are planning to develop wind power support for ships. Their proposal is to attach kite sails to ships and use the wind's power to help reduce diesel consumption and the fuel's impact on the environment.*
>
> Source: http://www.oecd.org/pisa/pisaproducts/pisa2012-2006-rel-items-maths-ENG.pdf

Berlin & White (1995) have observed that the increased use of mathematical modeling in appropriate applications in science class helped learners to recognize the connections between the two subjects [8]. In the science content areas, an example of a discipline specific integration might involve content and process skills in mathematics.

Examples from PISA 2012 that integrate science involve the mathematical graphic discipline in 'Climate Change' problem as the following [9]:

> *The burning of coal, oil and natural gas, as well as deforestation and various agricultural and industrial practices, are altering the composition of the atmosphere and contributing to climate change. …*



> *… Bars extending to the right of the center line indicate a heating effect. Bars to the left of the center line indicate a cooling effect. …*
>
> Source: http://www.oecd.org/pisa/38709385.pdf

Content Integration

The content integration involves selecting existing curriculum contents from mathematics area and one from science to weave together with objectives from two separate and distinct curricular. For example, suppose that the content for mathematics is 'collecting data' and the science content is 'motions of objects'. Then using the different objects move on the table, the learners record the data, draw graphs, and explain motions of objects in a straight line and in curves, the teacher allows the learners explore the connections between mathematics and science.

Process Skills Integration

Mathematics enables a learner to acquire skills to analyze various problems or situations, anticipate, plan, make decisions, solve problems and accurately and appropriately apply mathematics in daily life and serve as a tool for learning science, technology and other disciplines. Also, the learning area of science is aimed at enabling learners' link knowledge with processes for investigation and build knowledge through diverse practical work for systematic problem-solving, and for verifiable decision-making based on diverse data and evidences[10]. Through explanation of hypothesis and ideas, they make connections between problem-solving goals and the processes to achieve those goals [11]. Some of mathematical process skills and basic science process skills are shown in the following table [10]:

Mathematical process skills	Basic science process skills
- Problem Solving - Connection - Reasoning and Proof - Communication - Representation	- Observation - Classification - Measurement - Conclusion - Prediction - Communication

Collaborative Learning

Cooperative learning is a social process involving joint intellectual effort by learners or learners and teachers. Groups of students work together in investigation for understanding, meaning, and solutions or in creating a product.

In collaborative learning the feedback from peers or other team members are bound up with the success of the task. Individual learners assist others in solving problems and achieving their goals and everyone is expected to share credit for good ideas with others, and acknowledge others' skill experience, creativity, and contributions. Additionally, working with others includes process and interpersonal skills to support working cooperatively with others to achieve shared objectives, work cooperatively and have regard for others.

Working with graph – interpreting, creating, and employing, is an essential skill in learning sciences, especially in physics where relationships need to be derived. In this study, the content integration and process skills integration between mathematics and sciences were applied in topic of studying 'Tensile Stress-Strain Properties in Materials' between two different materials in order to encourage mathematics and science student teachers to contextualize the topic with respect to their existing knowledge and experience.

Method

Design

This study applied integrated learning mathematics and science as an activity allows teachers to focus on main concepts and process skills that are connected or interrelated between mathematics and science through model IDAC (**I**nvestigation, **D**iscussion, **A**nalysis, and **C**onclusion) as shown in the following figure:

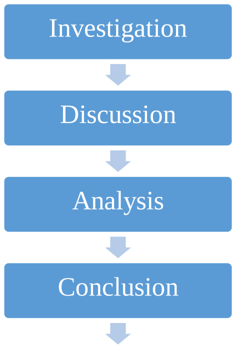


Figure 2. The IDAC model

Instruments

1. Experiment activities for using IDAC model on topic 'Tensile Stress-Strain Properties in Materials'

2. Self-assessment details on achieving the task and building the collaboration skills

Background and Specific Objectives

When designing structures such as bridges, structural engineers choose the materials by anticipating the forces they are expected to experience. Stress (σ) is the applied load divided by the material area. Strain (ε) is the elongation or contraction of a material per unit length of the material. According to Hooke's Law ($\sigma = E\varepsilon$) stress is dependent on strain in the material. The Young's modulus or the modulus of elasticity (E) is a constant associated with Hooke's Law and it is a parameter that indicates the stiffness of materials.

The students, upon completion of activities by using IDAC model will be able to

- Investigate the relationship between stress and strain
- Collaboratively develop procedures for testing tensile strength of materials using their existing knowledge
- Graph stress-strain curves for various materials, compare graphs and mechanical properties of materials.
- Analyze mathematical model showing the relationships between stress and strain related to the concept of Hooke's Law and Young's modulus.

Participants

The ***participants*** of this study were six graduate student teachers taking courses in teaching profession at Suan Sunandha Rajabhat University, network center under the Project for the Promotion of Science and Mathematics Talented Teachers--PSMT, supported by the Institute for Promotion of Teaching Science and Technology (IPST) in Thailand. All of students did not receive degree in education during their studies in undergraduate level.

Procedure

Activity for engagement: Before the activities begin, students are presented with very general problem which respect to existing knowledge and experience. In this study the students were asked questions to assess their previous knowledge about the relationships of two quantities by using line graph as shown in the following figure:

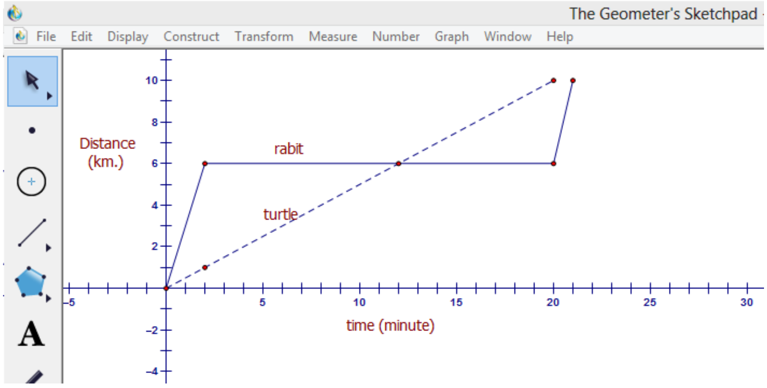


Figure 3. Graph of Rabbit and Turtle Racing

- What does the x-axis represent and what does the y-axis represent?
- Which animal ran faster, the rabbit or turtle? How can you know?
- The rabbit was hot and tired and decided to stop and take a nap, how far was rabbit from the starting point?
- The rabbit slept longer than he had thought and woke up, how long did the rabbit sleep?
- Which animal reach to the finish line first?

Activity for Integrated Learning: During the instruction, the teacher (as facilitator and researcher) observed students' behavior in doing the experiment using IDAC model on topic 'Tensile Stress-Strain Properties in Materials'. Group of six students (as participants) did the experiment based on the following plan:

1) Obtain materials with different elastic properties (from flexible to nonflexible). Investigate the elasticity of each material.

2) Brainstorm, create procedure to apply the stress to materials and design how to record the stress and change of materials' size.

3) Follow the experiment. Collect data, graph the stress (force) against strain (elongation) for each material.

4) Analyze and interpret graphed results about the relationships between stress-strain graph and elasticity of materials. Create mathematical model showing the relationships between stress and strain.

5) Conclude the results of relationships between the slope of linear portion in a stress-strain graph and the elasticity of materials related to the concept of Hooke's Law and Young's modulus.

Materials: 2 types of rubber bands with different elastic properties

Equipment: ring stands, ropes, clips, digital weighing balance,30 cm rulers, empty bottle, water

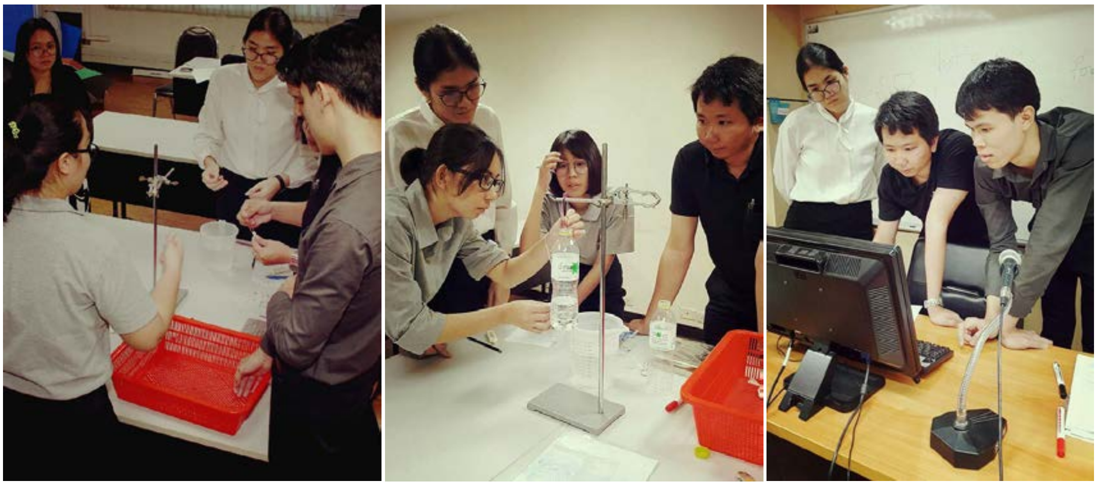


Figure 4. Students are doing the experiment using IDAC model on topic 'Tensile Stress-Strain Properties in Materials'.

Learning Activities:

Investigation: Students investigated elastic behavior of two types of bands (flexible and less flexible) and answer teacher's questions:

- What happens when you pull them? What happens when you let them free?
- If you stretch it really hard what might happen? How different between the 2 bands?
- Imagine if rubber band did not stretch and had to be made the exact size.
- Choosing materials of the right stretchiness can be very important but how to test the stretchiness of materials?

Discussion: Students brainstormed to create procedure to apply the stress to materials. As some of them had already known about the 'stress-strain graph', the teacher challenged them to use limited in-house equipment just as water bottle and weighing balance. There was discussion between teacher and students or among the students leaded to the results below:

- Stress can be applied to materials by hanging water bottles. The gravity force can be converted to the force that attracted objects using the relation:

$$\sigma = \frac{F}{A}$$

  where σ is stress, F is force, and A is the cross sectional area of the sample.
- The elongation can be measured be the extension of rubber band's length (ΔL). The strain can be calculated by the following formula:

$$\varepsilon = \frac{\Delta L}{L_0}$$

  where L_0 is the original length of a band, and ΔL is the extension of the stretched band.
- Avoid using the ropes because it has own modulus which will interfere the result.

Students shared their ideas how to sketch the graph illustrated the relationships between stress and strain of rubber bands. Students used Microsoft Excel to calculate the stress (σ), strain (ε) and drawing the stress-strain graph. Once the experiment had finished, the teacher encouraged the students to predict the stress-strain curve of the other bands with less elasticity: below or above stress-strain curve of the first one.

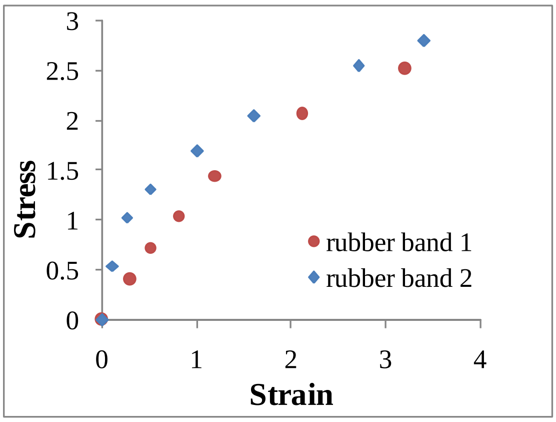


Figure 5. The stress-strain graph of two rubber bands.

Analysis: Students analyze and interpret graphed results of two different materials - flexible and less flexible - in order to get the concepts of 'Modulus' or 'Elasticity' of materials by formulate the questions. For examples,

- Which materials did you pull harder?
- How far each material has stretched after applying the same amount of force?

Conclusion: Students concluded the simple definition of stress and strain as follows: ***Stress*** is how hard you are pulling. ***Strain*** is how far the material has stretch and ***Elasticity*** states how much a material will stretch as a result of a given amount of force. Elasticity of different materials can be compared by comparing the slope of stress-strain graph.

Consolidating: Teacher showed the universal testing machine, which used to test the tensile strength and compressive strength of materials. The concept of Hooke's Law and Young's modulus were also introduced to the students. Students searched and compare approximate Young's modulus for various engineering materials like iron steel and concrete. Test out the ideas, how their stress-strain graph look like?

Evaluation: After the instruction, the teacher provided students' self-evaluation for integrated learning reflection by rating their task achievement and behavioral indicators.

Statistical Analysis

Analyze the effect of integrated learning mathematics and science by determining the rating of self-assessment for two categories: task achievement (9 indicators) and building the collaboration skills (9 indicators), according to the following scales:

4 ----- I do this very well. I am consistent and successful in the integrated learning.

3 ----- I am good at this. With some practice I can make it perfect.

2 ----- I am getting better, but still need to work on this a bit more.

1 ----- I am not particularly good at this integrated learning.

Results and Discussion

Students' self-evaluation for task achieving were above '***good level***' towards the effect of integrated learning mathematics as shown in the following Table:

Table 1 Results of Students' Self-Evaluation on Task Achievement

Indicators	M1*	M2*	M3*	S1**	S2**	S3**
1. Give and seek input from others in identify the problem.	4	4	4	3	4	3
2. Assist others define the context in solving problems and achieving own goals.	3	4	4	4	4	3
3. Share information and ideas to enumerate the choices and the all possible options in doing task.	4	3	4	4	4	3
4. Ask for help in analyzing the options for achieving goals and solving problems.	4	3	4	3	3	4
5. Check for agreement, and gain commitment to shared goals.	3	3	3	3	3	2
6. Notify others of changes or reasons explicitly to problems in a timely manner.	3	3	4	3	3	3
7. Make procedural suggestions to encourage progress towards goals.	3	4	4	3	4	3
8. Check for understanding to connect ideas to realistic actions.	3	4	3	3	3	4
9. Conclude with a reflective discussion.	4	3	3	3	3	3

Remark: * M1, M2, M3 represent three math ed. student teachers; ** S1, S2, S3 represent three science ed. Student teachers

In Table 1, all of mathematics education student teachers rated at '***very good level***' for indicator 1. This illustrated that they got new experiences in giving and seeking input information from other member, especially basic science process skills.

For students' self-evaluation on building collaboration skills, the rating were above '***good level***' towards the effect of integrated learning mathematics and science on critical and collaboration skills as shown in the following Table:

Table 2 Results of Students' Self Evaluation on Collaboration Skills

Indicators	M1*	M2*	M3*	S1**	S2**	S3**
1. Give and receive feedback from peers or other team members in order to perform the task.	4	4	4	4	4	2
2. Share credit for good ideas with others.	4	3	4	3	4	3
3. Acknowledge others' skill, experience, creativity, and contributions.	4	4	4	3	4	3
4. Listen to and acknowledge the feelings, concerns, opinions, and ideas of others.	3	4	4	3	4	4
5. Expand on the ideas of a peer or team member.	4	4	3	4	4	2
6. State personal opinions and areas of disagreement tactfully.	3	3	3	3	3	3
7. Listen patiently to others in conflict situations.	3	3	4	3	3	3
8. Define problems in a non-threatening manner.	3	3	4	3	3	3
9. Support group decisions even if not in total agreement.	4	4	3	3	3	2

Remark: * M1, M2, M3 represent three math ed. student teachers; ** S1, S2, S3 represent three science ed. Student teachers

In Table 2, all of mathematics education student teachers rated at '***very good level***' for indicator 1 and indicator 3. This illustrated that they got new experiences in giving and receiving feedback from peers or other team members in order to perform the task, and also acknowledge others' skill, experience, creativity, and contributions.

During the process of experiment, the students collaborated with each other to solve problems involving relationships among variables and to generate mathematical solutions to complex the real-world problems, created and used an algebraic model of a functional relationship incorporating multiple quantities. Teachers should develop integrated learning plan before implementing this model in classroom that composing of some topics in the following example:

<table>
<tr><td colspan="2">Support</td></tr>
<tr><td colspan="2">Teacher collaboration: Mathematics and/or Science
Knowledge: Mathematics and/or science
Specialists: Mathematics and/or Science
Professional Development Programs
Curriculum Materials</td></tr>
<tr><td colspan="2">Teaching</td></tr>
<tr><td>Lesson Planning</td><td>Classroom Practice</td></tr>
<tr><td>• Focus on connections
• Problem-based
• Student-centered
• Real world contexts
• STEM approached
• Etc.</td><td>• Questioning techniques: before, during, and after lesson
• Integrated disciplines, contents, and process skills
• Justify thinking: critical and creative
• Cooperative learning
• Technology-based learning
• Etc.</td></tr>
<tr><td colspan="2">Efficacy</td></tr>
<tr><td colspan="2">• Mathematics literacy involves in science processes
• Science literacy involves in mathematics processes
• Supporting the 21st Century Skills for students</td></tr>
<tr><td colspan="2">Learning Resources</td></tr>
<tr><td colspan="2">• Materials/equipment for activities
• Technology resources
• Computer Programs
• Etc.</td></tr>
</table>

Conclusion

Lessons which integrate Mathematics and Science require the content to be contextually based and taught in an integrated learning with mathematics process skills and basic science process skills. As integrated learning embodied many of these process skills, the researchers took inspiration from this approach to create a model specific to the integrated learning of Mathematics and Science: Investigation, Discussion, Analysis, and Conclusion (IDAC). This model was designed with secondary education in mind but can be adopted within a higher education setting, especially student teacher with background non-degree in education. It is based around two characteristics: Critical Thinking resulting in Higher-Order Learning and Collaboration Skills resulting in social communication and creativity; applicable to the 21st Century Skills in globally competitive age.

Acknowledgement

We would like to express our special thanks of gratitude to Suan Sunandha Rajabhat University (SSRU) and Institute for Promotion of Teaching Science and Technology (IPST) who gave us the opportunity to do this study.

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