INTRODUCTION

The Thinking Programme in Singapore schools was implemented in all secondary schools by 1999. Thinking skills are taught explicitly as well as infused in Science, Mathematics, English, History and Geography in Secondary One and Secondary Two. These thinking skills are further reinforced in Secondary Three and Secondary Four. Students are also encouraged to transfer the skills learned in these five chosen subjects to others.

The framework adopted for the Thinking Programme is the Dimensions of Learning framework (Marzano et al., 1997). This framework is based on the premise that all learning involves thinking. In particular, it involves the interaction of five types, or dimensions, of thinking.

Dimension 1: Positive attitudes and perceptions about learning
- Classroom climate
- Classroom tasks

Dimension 2: Thinking involved in acquiring and Integrating knowledge
- Declarative Knowledge
  - Constructing meaning
  - Organising
  - Storing
- Procedural Knowledge
  - Constructing models
  - Shaping
  - Internalizing

Dimension 3: Thinking involved in extending and refining knowledge
- Comparing
- Classifying
- Inducting
- Deducting
- Analyzing
- Abstracting
- Constructing support
- Analyzing perspectives

Dimension 4: Thinking involved in using knowledge meaningfully
- Decision-making
- Investigating
- Experimental inquiry
- Invention
- Problem solving

Dimension 5: Productive habits of mind
- Critical thinking
- Creative thinking
- Self-regulation

Teaching thinking skills alone does not ensure that they will be learned, internalized and applied by students. It is often the assessment tail that wags the learning dog! Students tend to adopt a learning
approach that matches the assessment demands. Hence it is imperative that assessment must match the objectives of teaching thinking skills. Test and examination items must be designed to assess thinking skills.

This article attempts to illustrate how Dimensions 2, 3, and 4 of Marzano's framework can be infused into lessons and test items in lower secondary science. Five sample tasks that aim to teach and assess thinking in lower secondary science are described. Tasks in each of the three streams, Express, Normal Academic, and Normal Technical, are included. Table 1 provides a summary of the tasks. All the tasks involve chemistry concepts.

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Level</th>
<th>Stream</th>
<th>Topic</th>
<th>Type of Task</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Sec 1</td>
<td>Express/Special</td>
<td>Separation Techniques</td>
<td>Theory Lesson</td>
</tr>
<tr>
<td>3</td>
<td>Sec 2</td>
<td>Normal Academic</td>
<td>States of Matter</td>
<td>IT Lesson</td>
</tr>
<tr>
<td>3</td>
<td>Sec 1</td>
<td>Normal Academic</td>
<td>Physical and Chemical Changes</td>
<td>Assessment Task</td>
</tr>
<tr>
<td>4</td>
<td>Sec 1</td>
<td>Normal Technical</td>
<td>Properties of Matter</td>
<td>Project Work Task</td>
</tr>
<tr>
<td>4</td>
<td>Sec 2</td>
<td>Express/Special</td>
<td>Solubility</td>
<td>Practical Task</td>
</tr>
</tbody>
</table>

**DIMENSION 2 TEACHING TASK**

**The Lesson**
This is a lesson on distillation for Secondary One Express/Special to help students acquire declarative knowledge. This lesson aims to help students construct a mental model of the distillation process.

**The Classroom Discourse**
The teacher introduces the lesson by showing students a lump of table salt and a piece of ice. She asks students to predict what happens to each sample when left at room temperature and when heated. She provides a summary of all the responses by stating that solids melt and liquids vapourise when there is sufficient heat. She also draws students' attention to the fact that room temperature is high enough for ice to melt but not high enough for table salt to do likewise. She shows students a table of melting points and boiling points of the two samples. The teacher proceeds to show students part of a CD-ROM that depicts particulate movements in solids and gases. Students are encouraged to compare the two movements.

She begins the developmental part of the lesson by demonstrating the distillation of a solution that she prepares from the water from the melted ice and table salt. Students observe the entire process. One student is asked to observe changes in the thermometer. Another is asked to observe changes in the conical flask at the outlet of the condenser. The first student reports that the thermometer reading increases and then remains constant before it increases further. The other reports that colourless liquid is trickling from the condenser. The teacher begins to help students construct a model of the processes that contribute to the observations by posing the question 'What has happened?'.

_A scene from the classroom ..._

Teacher: Let us see what has happened. What has happened to the molecules in water and the particles in table salt?
Teacher: Let Danny be one water molecule and Azan be one salt particle. (She gets two students to role-play).
Teacher: In the beginning, how does Danny the Water and how does Azan the Salt move? (She invites responses.)
Teacher: Next, heat is supplied. Danny the Water, how are you moving now? Azan the Salt, how are you moving now? (She encourages the students to role-play the movements.)

Teacher: Subsequently, at 100°C, what happens? What happens to Danny the Water? What happens to Azan the Salt?

There is much laughter in the class. A table such as Table 2 is used to record students' responses.

Table 2: Students' Responses

<table>
<thead>
<tr>
<th>Time</th>
<th>Temperature</th>
<th>What happens to water molecules?</th>
<th>What happen to salt particles?</th>
</tr>
</thead>
<tbody>
<tr>
<td>At first …</td>
<td>Room temperature</td>
<td>Moves freely in the flask. Water is liquid.</td>
<td>Moves freely in the flask. Salt is a solution.</td>
</tr>
<tr>
<td>Then …</td>
<td>100°C</td>
<td>Moves faster but still remains in the flask. Water remains a liquid.</td>
<td>Moves faster but still remains in the flask. Salt is still a solution.</td>
</tr>
<tr>
<td>Finally …</td>
<td></td>
<td>Moves very fast. Water becomes steam. Escapes the flask. Moves into the condenser. The condenser is cooler. Slows down. Steam becomes liquid again.</td>
<td>Still remains in the flask. Salt remains a solution. When all the water has left the flask, salt becomes a solid.</td>
</tr>
</tbody>
</table>

Construction of Mental Model
The process of mental model construction for a complex, microscopic and dynamic process such as distillation is achieved through:

- considering simultaneous events (behaviour of water molecules and salt particles) separately and linking them on a common timeline.
- focusing on a specific object (molecules and particles).
- tracing events on a timeline.
- linking microscopic events to macroscopic events through role-play.

DIMENSION 3 TEACHING TASK

The Lesson
This is an IT-based lesson for Secondary Two Normal Academic to help students extend and refine their knowledge on the states of matter. This is achieved by providing opportunities for pupils to compare and classify materials whose category is fuzzy.

The Use of Information Technology
The power of technology is unleashed in the form of animation. As the modelling of behaviour of particles in each of the three states relies on the description of particulate movement, the animation provides a vivid simulation. This in turn provides students with a concrete model of the concept.

The consolidated information on various materials provides a convenient and easily accessible resource for students' investigative work. Students learn about the properties, abstraction, composition and application of the various materials with excellent, life-like photographs without having to be transported to the actual scene or to be brought the actual materials.

The Infusion of Thinking Skills
The need for comparison, clarification and classification provides an excellent platform for students to extend and refine their knowledge on the three states of matter. The choice of materials with fuzzy classification requires students to reflect on their initial understanding of the three states. The courseware allows students to verify their classification. Through a process of classification, students
go through the cycle of predicting, verifying and analysis to reinforce, refine and extend their conceptual understanding of the theory.

Encouraging Productive Habits of Mind
Classroom discourse is encouraged through pair discussions and group presentations. As students discuss in pairs to classify the materials, they need to articulate their understanding. The need to defend and justify one’s classification during the oral presentation encourages students to evaluate their own thinking. Thus, the classroom discourse requires students to engage in productive habits of mind.

Figures 1 to 4 shows the lesson plan and worksheets used in the learning task.

<table>
<thead>
<tr>
<th>Specific Instructional Objectives</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pupils should be able to classify a given material as one of the three states of matter.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Thinking Skills</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Classifying</td>
</tr>
<tr>
<td>• Predicting</td>
</tr>
<tr>
<td>• Verifying</td>
</tr>
<tr>
<td>• Analysing: Patterns and Relationships</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Learning and Teaching Materials</th>
</tr>
</thead>
<tbody>
<tr>
<td>2. Worksheet A and Worksheet B (Copy 1 &amp; Copy 2)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Learning Environment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Half Computer Laboratory</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Instructional Strategies</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Using the CD-ROM, teacher explains, illustrates and differentiates how particles behave in each of the three states of matter.</td>
</tr>
<tr>
<td>2. Without reference materials, students individually describe, in their own words, their understanding of each of the states of matter using Worksheet A.</td>
</tr>
<tr>
<td>3. Students then work in pairs. The whole class is further divided into two big groups, namely A and B. Each pair in Group A is given a copy of Worksheet B (Copy 1). Each pair in Group B is given a copy of Worksheet B (Copy 2).</td>
</tr>
<tr>
<td>4. The teacher explains the task.</td>
</tr>
<tr>
<td>□ Through pair discussions, students classify the two materials listed in Worksheet B as a solid, liquid or gas.</td>
</tr>
<tr>
<td>□ They are also required to justify and explain their classification.</td>
</tr>
<tr>
<td>5. Each pair of students is then given a copy of the CD-ROM to work on the computer. The teacher demonstrates how the CD-ROM is used to verify the classification of materials into the three states of matter, as well as to investigate the nature of other materials. Students then complete the rest of Worksheet B based on information that they gathered from the CD-ROM.</td>
</tr>
<tr>
<td>6. Two groups from each half of the class investigating different materials then present their findings to the class. The audience is encouraged to seek clarification from the presenters, and it is the presenters’ duty to convince the audience on the appropriateness of their classification.</td>
</tr>
<tr>
<td>7. The teacher concludes by summarising the key points presented and points out any misconception that students might have displayed.</td>
</tr>
<tr>
<td>8. Students then complete Worksheet A individually, making modifications, if any, to their initial description of each state of matter.</td>
</tr>
<tr>
<td>9. All Worksheets are submitted at the end of the lesson for the teacher to evaluate students’ learning.</td>
</tr>
</tbody>
</table>

Figure 1: The Lesson Plan
### SECONDARY 2 Normal Academic

#### WORKSHEET A

**TOPIC - THE THREE STATES OF MATTER**

<table>
<thead>
<tr>
<th>States of Matter</th>
<th>Describe each state of matter in your own words.</th>
<th>Modifications, if any, of your description of each state of matter after completing Worksheet B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solids</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Liquids</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gases</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 2: Worksheet A

### SECONDARY 2 Normal Academic

#### WORKSHEET B

**TOPIC - THE THREE STATES OF MATTER**

Complete the table.

<table>
<thead>
<tr>
<th>Material</th>
<th>Classify it as a solid, liquid or gas.</th>
<th>Explain your classification</th>
<th>What is the classification provided by the CD-OM?</th>
<th>What did you learn about the substance from the CD-ROM?</th>
<th>Do you agree with the classification given by the CD-ROM? Explain.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rice</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yoghurt</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 3: Worksheet B (Copy 1)

### SECONDARY 2 Normal Academic

#### WORKSHEET B

**TOPIC - THE THREE STATES OF MATTER**

Complete the table.

<table>
<thead>
<tr>
<th>Material</th>
<th>Classify it as a solid, liquid or gas.</th>
<th>Explain your classification</th>
<th>What is the classification provided by the CD-OM?</th>
<th>What did you learn about the substance from the CD-ROM?</th>
<th>Do you agree with the classification given by the CD-ROM? Explain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Toothpaste</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 4: Worksheet B (Copy 2)
DIMENSION 3 ASSESSMENT TASK

This section describes a paper-and-pencil test item that requires students to perform the process of comparing to extend and refine their knowledge of observed changes. This item is for Secondary One Normal Academic based on the topic of physical and chemical changes. Figure 5 shows the item.

Water is made up of two elements, hydrogen and oxygen.
A beaker of water is used in distillation.
Another beaker of water is used in electrolysis.

a. Compare the process of distillation and the process of electrolysis by underlining the correct answers.

<table>
<thead>
<tr>
<th>What type of energy is needed to carry out the experiment?</th>
<th>Distillation</th>
<th>Electrolysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>What is collected at the end of the experiment?</td>
<td>Hydrogen / Oxygen / Water</td>
<td>Hydrogen / Oxygen / Water</td>
</tr>
</tbody>
</table>

b. Based on your answers, state how distillation is different from electrolysis.

Assessment of Thinking Skills
In this test item, students are guided to use a thinking skill, comparing, to extend and refine their knowledge. In part (a), students are assessed on their declarative knowledge. In part (b), students are assessed on their ability to extend this declarative knowledge. Students who are able to extend their declarative knowledge would state that distillation requires less energy (heat) than electrolysis (electrical), or they would be able to state that there is no new product in distillation while there are new products in electrolysis. The test items provides a framework for students to engage in the process of comparing to extend their declarative knowledge about the two processes to the fact that these processes belong to different categories of changes.

DIMENSION 4 PRACTICAL TASK

The Lesson
This is a practical task that requires students to investigate the effect of temperature of a solution on the solubility of solute. The lesson is for Secondary Two Express/Special.

Using Knowledge Meaningfully
In this lesson, students revisit their knowledge and skills in differentiating a suspension from a solution, in separating a solid in a suspension, and in determining whether a solid is soluble in a liquid. Students’ performance in this lesson provides a good indicator of their ability to use their knowledge and skills meaningfully to investigate a new problem situation. The new problem situation is the solubility of salt at different temperature. Besides, the experience gained in cooling the saturated salt solution also provides a good introduction to the concept of crystallisation.

Figure 6 shows the experiment.
Aim: To investigate how the solubility of a solute is affected by the temperature of the solution.

Apparatus: Measuring cylinder, 3 beakers, 1 large beaker, thermometer, spatula, filter paper, filter funnel, bunsen burner, tripod stand, wire gauze

Materials: common salt, water and ice

Procedures and Observations

1. Measure 20 cm$^3$ of water using a measuring cylinder. Pour the water into a beaker.

2. Use a thermometer to measure the temperature of the water. Record this temperature, then remove the thermometer from the beaker.
   Temperature of water: ...........°C

3. Add a spatula of salt to the water in the beaker. Gently stir the mixture in the beaker with a glass rod for about one minute.

   ![Salt mixing](image)

   Observe and record whether the salt has dissolved. State whether the salt is soluble, slightly soluble or insoluble in water.

4. Repeat step 3 as many times as it is needed for the mixture in the beaker to be a suspension. Describe how you decide that the mixture in the beaker is indeed a suspension.

   Can you still be sure about the solubility of salt in water? What do you think might have happened?

5. Place a filter paper into a filter funnel. Pour the suspension from the beaker into another beaker. What do you think is the filtrate in the second beaker?

6. Using a bunsen burner and the tripod stand, heat the filtrate until its temperature reaches 70°C.
7. Add a spatula of salt to the filtrate in the beaker. Gently stir the mixture in the beaker with a glass rod for about one minute. Observe and record whether the salt has dissolved.

Describe what factor might have contributed to your observation.

Repeat step 7 as many times as it is needed for the mixture in the beaker to be a suspension again. What do you think might have happened now?

8. Place a filter paper into a filter funnel. Pour the suspension from the beaker into another beaker.

What do you think is the filtrate in the second beaker?

9. Place the beaker of filtrate into the bigger beaker containing ice.

Cool the filtrate until the temperature is 20°C. Observe and record any changes to the filtrate.

Describe what factor might have contributed to your new observation.

Conclusion

Based on the observations you made, summarise your conclusion in a sentence.

Figure 6: The Experiment

**DIMENSION 4 PROJECT WORK TASK**

This is a project work task for Secondary One Normal Technical students. In this task, students are using their knowledge of properties of materials to create a useful product (invention).

Figure 7 shows the project work instruction sheet.

You are provided with samples of two materials (copper wire and rubber band). Perform the following experiments on the two samples.
Experiments

Heat 5g of the material in a crucible.

Hang 20 cm of the material from a retort stand.
Hang a weight to its end.

Connect 20 cm of the material to an incomplete electrical circuit of a cell, bulb and wires.

The instructions can be given using diagrams.

Observations

<table>
<thead>
<tr>
<th>Copper</th>
<th>Rubber</th>
</tr>
</thead>
</table>

You are required to make a useful household product.
The product must use at least one of the two materials.
Make a brochure to explain the product's usefulness.
The brochure must state all the materials used to make the product and why they are chosen.
You will act as a salesperson to promote this product at a fair.

Figure 7: Project Work Instruction Sheet

Using Knowledge Meaningfully

The task satisfies the five requirements of project work tasks (Ministry of Education, 1999). It is interdisciplinary as it links Science (properties of materials) with Technical Studies (technical drawing and constructing the product), English (writing the content of the brochure) and Computer Studies (designing and producing the brochure). Simple research of the properties of materials as well as the product they are making is required. The task also requires collaboration, oral presentation and provides opportunity to help students acquire life skills.

CONCLUSION

Though science teachers have been using scientific inquiry in their lessons and practical sessions, they may not have done so explicitly. The introduction of the Thinking Programme in Singapore schools has highlighted and made explicit the different types of thinking skills crucial to critical and creative thinking and in problem solving. The power of information technology can be skilfully harnessed into the teaching and learning of content subjects, including science. The power of animation is especially useful in helping student think at a microscopic level.

In this article, we attempt to illustrate how lower secondary science teachers could implement a thinking curriculum based on the Dimensions of Learning framework through teaching activities, practical tasks, IT-based lessons, project work and test items.

REFERENCES


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