Developing Thinking Skills in Malaysian Science Students Via An Analogical Task

Maria Salih
Faculty of Science and Technology,
Sultan Idris University of Education
Malaysia

Teaching thinking skills to students is often associated with a thinking strategy or a specific thinking technique. The strategy or technique may refer to a series of steps that is systematically drawn up to ensure that the teaching of thinking skills takes place effectively. In the case of Malaysia, a conceptual framework of Thinking Skill Thinking Strategy (TSTS) was constructed by the Curriculum Development Centre to infuse thinking in students. The TSTS framework (Malaysia, Curriculum Development Centre, 2001) found in the Science Curriculum Specification acts as a guide for teachers to teach the skills during the teaching and learning process. The purpose of this paper is to discuss the potential of an analogical task in accelerating the thinking skills of Malaysian students in the teaching and learning of an abstract biology concept. The analogical task given to 99 biology students seemed to enhance the various thinking skills depicted in the TSTS framework. As the students strive to generate their respective analogies, their reasoning capabilities, creative and critical thinking skills as well as their thinking strategies developed significantly.

Key words: Thinking skills; Thinking strategy; Science; Analogical task; Curriculum; Teaching and learning

Introduction

The ability to acquire thinking skills is an important aspect for students to optimise their thinking capabilities. This in turn will perhaps increase their problem solving and critical and creative thinking abilities. As such, it is the main concern of most educators presently, to help students to become effective thinkers so as to enable them to think critically and to solve problems. As suggested by Langer (1991), students of today need to ascertain
the types of critical thinking skills required in order to use the recent communication technologies that they meet daily in their everyday living and in entry-level jobs. Langer’s (1991) statement is agreed upon by Rajendran (2004), when he explains why students need to prepare themselves to receive information; interpret, analyse or manipulate the information; critically think about the information and finally draw conclusions, make inferences or generalisations regarding the information. Rajendran (2004) also emphasise the need for students to make predictions, propose solutions, create, judge ideas, express opinions, make choices and decisions and solve everyday life-like problems.

Realising the importance of teaching thinking skills to all students, science teaching and learning in the Malaysian school context has progressed significantly over the years. The scenario of the Malaysian classroom has also shifted gradually from the once conventional mode of chalk-and-talk delivery to more hands-on and minds-on teaching and learning activities with the aid of sophisticated instructional tools such as the multimedia. These instructional innovations and development in the teaching and learning processes are aimed at producing good thinkers and problem solvers. To support this, one of the main objectives of the Malaysian science curriculum is to enhance the reasoning abilities of students which is hoped to be achieved by emphasising science process skills, manipulative skills, critical and creative thinking skills that have been consciously introduced into the new Malaysian Science Curriculum (Malaysia, Curriculum Development Centre, 2001). These skills are carefully and systematically planned using the various teaching approaches such as inquiry and problem solving via a Thinking Skill Thinking Strategy (TSTS) framework (Malaysia, Curriculum Development Centre, 2001). One such approach to develop thinking skills in Malaysian science students is via an analogical task as depicted in the TSTS framework (see Figure 1).
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The conceptual framework of TSTS as shown in Figure 1 is divided into creative thinking and critical thinking (Malaysia, Curriculum Development Centre, 2001). Creative thinking is the ability to generate and assimilate new genuine ideas. The new and genuine ideas generated are products of the individual’s aspiration and a collection of existing ideas. Critical thinking is the ability to evaluate and rationalise the existing and new ideas. Alternatively, thinking strategy is a slightly higher thinking process that incorporates several steps. Each individual step in-turn comprises of several creative and critical thinking skills. In the process of conceptualisation, problem solving and decision making, both creative and critical TSTS is

Note:
Analogise* - generate analogies by the process of comparing and contrasting for similarities and differences between the existing ‘source’ concept and the ‘target’ concept being learnt (Maria 2008).

Figure 1. Conceptual framework of Thinking Skill Thinking Strategy (TSTS).
(Malaysia, Curriculum Development Centre, 2001)

The conceptual framework of TSTS as shown in Figure 1 is divided into creative thinking and critical thinking (Malaysia, Curriculum Development Centre, 2001). Creative thinking is the ability to generate and assimilate new genuine ideas. The new and genuine ideas generated are products of the individual’s aspiration and a collection of existing ideas. Critical thinking is the ability to evaluate and rationalise the existing and new ideas. Alternatively, thinking strategy is a slightly higher thinking process that incorporates several steps. Each individual step in-turn comprises of several creative and critical thinking skills. In the process of conceptualisation, problem solving and decision making, both creative and critical TSTS is
utilised. On the contrary, reasoning skills helps in assisting a logical, rational and fair consideration towards all TSTS employed. The development of thinking skills is not a natural occurrence, neither is it an accidental outcome of experience or an automatic by-product of study in a subject area (Beyer, 1987). It requires deliberate, continuing instruction and practice in order to develop thinking skills to its full potential (Beyer, 1987; Thoms, 1998)

Analogical Learning

An analogy is defined as a concrete and visualisable representation of the similarities (matches) and differences (mismatches) between the ‘source’ and ‘target’ concepts (Maria, 2004). The ‘target’ is the unfamiliar abstract material to be learnt. It could be a concept, principle, procedure (Reigeluth, 1980), theory (Weller, 1970), or problem solving (Gick & Holyoak, 1980). The ‘source’ concept is a familiar visualisable material to the student that is obtained from the surroundings or from a situation in the environment such as a thing (living and non-living), process, system, place or an activity (Maria, 2004). The term ‘match’ and ‘mismatch’ describes the interaction between the ‘target’ and the ‘source’ concept (Maria, 2004). A ‘match’ occurs when the interaction between the ‘target’ and the ‘source’ concepts focuses upon similar characteristics and a ‘mismatch’ occurs as the interaction comes across differences between the ‘target’ and the ‘source’ concepts (Maria, 2004). Different people will define analogy differently. For example, Gentner (1983, 1987) defined analogy as the mapping of a system of relations from the ‘base’ to the ‘target’ while Treagust (1993) defined analogy as a process of identifying similarities between two concepts. The term analogy is not applicable when the shared similarities (matches) between the ‘source’ and ‘target’ concepts are identical (as in the example of one human eye and the other) or literally similar (a human eye and the eye of another mammalian, e.g a dog) (Ortony, 1979 & Gentner, 1980). A frequently used analogy in science is the ‘camera’ that is used to represent the ‘human eye’ (Glynn, 1995) as shown in Figure 2.
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Figure 2. The eye-camera analogy (Glynn, 1995).

The mapping of the different components of the ‘source’ (camera) and ‘target’ (eye) concepts in the analogy is shown in Table 1 (Glynn, 1995).

Table 1
Camera Analogy of the Human Eye (Glynn, 1995)

<table>
<thead>
<tr>
<th>Some shared features/matches between a camera and a human eye</th>
<th>Eye (target)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Camera (base/source/analog)</td>
<td></td>
</tr>
<tr>
<td>Lens</td>
<td>Lens</td>
</tr>
<tr>
<td>Aperture</td>
<td>Pupil</td>
</tr>
<tr>
<td>Diaphragm</td>
<td>Iris</td>
</tr>
<tr>
<td>Film</td>
<td>Retina</td>
</tr>
<tr>
<td>Inverted image</td>
<td>Inverted image</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Unshared feature/mismatch between a camera and a human eye (where the analogy breaks down)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A camera is focused by changing the distance between the lens and the film</td>
</tr>
</tbody>
</table>

An analogy acts as the mediator between existing knowledge and new knowledge. It was shown by researchers such as Hewson and Hewson (1992); Strike and Posner (1992); Demastes, Good, and Peebles (1996) and Duit and Treagust (1997) that the activity of building relations between students’ existing knowledge and the new knowledge plays a significant role in interpreting students’ learning as a process of conceptual change. In the case of simple and familiar analogies, they act as schemas where the students use to form meaningful understandings of the abstract science concepts. According to Glynn and Duit (1995), Iding (1997) and Lehrer and Schauble
(1998), as the students develop cognitively and learn more science, they would adopt more sophisticated and powerful explanatory models.

**Analogical Reasoning**

Analogical reasoning as described by Vosniadou and Ortony (1989) is the ability to transfer relational information from the ‘source’ or ‘base’ domain to the ‘target’. The author refers analogical reasoning as the thinking processes that occur in the human mind as one tries to generate analogies of a specific concept (Maria, 2004). These thinking processes that take place in the minds of the students were postulated through a Self-Generated Analogical Reasoning Model, SGAR (Maria, 2004) to depict analogical reasoning. The analogical reasoning process proceeds in three phases namely, 1) Reception phase, 2) The Interaction phase and 3) The Emergent phase (Maria, 2008).

In the **Reception** phase, the learner is exposed to the ‘target’ concept or the abstract science concept to be learnt. This includes all the relevant and pertinent sub-concepts that clearly explain the whole abstract science concept. In cases where the analogy and analogy generation is new and unfamiliar to the learner, the introduction and exposure of analogies and analogy generation is necessary to familiarise them. This is followed by the **Interaction** phase whereby the process of analogy generation involves several variables such as students’ emotions, external and internal stimuli, social interaction, and visual representation. The third or final stage in the SGAR model is the **Emergent** phase. The types and complexity of the analogies generated, the types of matches and mismatches observed, responses to the mismatches and the skills acquired are some of the identifiable variables in the self-generated analogical reasoning process (Maria, 2008). Some of the thinking skills and thinking strategies such as generate ideas, relate, compare and contrast, reason, create, evaluate and making inference as listed in the TSTS framework (Refer Figure 1) were observed in the above three phrases of analogy generation and will be discussed in detail in the section on findings in this paper.
Analogical Task
An analogical task is a specific task or an activity embarked upon by an individual to generate or produce analogies of a particular concept (Maria, 2004). The analogical task used in the study was the Translation Analogy Task (TAT). It was a task of generating analogies for 'translation' which is the 'target' biology concept in protein synthesis.

Methodology of the Study
Qualitative data collecting procedures was used to gather information for this study. The analogical task was administered and the students’ written journals were used to explore how the students generated analogies. Students’ analogical reasoning was also explored through the structured interviews administered and this was triangulated with the students’ analogical task and the researcher’s personal observations made throughout the entire data collection period. These were the non-participant classroom observations and observations during the administration of the TAT and the interviews. The non-participant classroom observation was carried out throughout the four, one-hour lecture of protein synthesis. The observation was mainly focused on the lectures carried out by the biology coordinator and teacher, the teaching and learning materials used and the information about translation that was imparted to the students. During the TAT, observations were also carried that focused on how the students performed the task, that is, whether they communicated with each other or the researcher, or whether they made any references on translation. Since the interviews were audio taped, the researcher could note down observations during the interviews. The observations during the interviews were planned to capture the students’ external expressions and perspective regarding the TAT and the process of analogy generation via their behaviour, body gestures and facial expression. The observations made during the interviews also helped to support the interview transcripts. Observations were also conducted to triangulate emergent findings together with interview data and document analysis (Merriam, 1998) which further helped to support the research findings.

The respondents comprised of 99 (36 males and 63 females) science students from a matriculation college in the vicinity of Kuala Lumpur, Malaysia. Their age group ranged from 17 to 19 years. The matriculation
programme of the Ministry of Education, Malaysia is a preparatory programme for students to help qualify them into pursuing a degree course in science, technology and accounts in the public and private universities. All the participants had sat for the *Sijil Pelajaran Malaysia* (Malaysian Certificate of Examination) which is a national examination conducted at the end of the fifth year of secondary education. All the 99 respondents were asked to think and generate analogy for ‘translation’ by writing down everything that they did or thought of during the process of generating the analogy. They were allowed to refer to any form of reference. Each student was given the task of writing a journal report after they had finished generating their analogies. The journal reports would give them some freedom to relate what was in their minds during the analogy generation. This was thought of as an alternative method to the ‘think aloud protocol’. It was also the researcher’s intention for the students to generate the analogies individually. The reason for this was to gather as much information as possible regarding each individual’s analogical reasoning pertaining to the analogies generated.

*Sources of Data*

Table 2 shows the sources of data obtained from the various instruments used in the study.

Table 2

<table>
<thead>
<tr>
<th>Sources of Data</th>
<th>Data obtained</th>
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<tbody>
<tr>
<td>Analogical Task</td>
<td>Students’ generated analogies</td>
</tr>
<tr>
<td>Interview</td>
<td>Students’ interview excerpts</td>
</tr>
<tr>
<td>Observation of analogy generation</td>
<td>Researcher’s audit trail (data obtained would be the field notes)</td>
</tr>
<tr>
<td>Students’ journal</td>
<td>Analysis of document (data would be their notes)</td>
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</table>

The qualitative data provided the ‘depth’ and ‘richness’ of the students’ thinking in generating analogies for the concept of translation. The interviews were used to probe the students so as to capture more information pertaining to the analogical reasoning occurring in the minds of the students. Other data obtained from the students’ journals, researcher’s observations and audit trail helped triangulate the findings of the interview data.
An audit trail was kept to record all the daily activities, discussion with peers and advisors and flow of ideas on a day to day basis. It was somewhat like a personal journal whereby new ideas could be built up as the analysis proceeded with more and more data coming in. This was important because it allowed monitoring of data collection as the analysis proceeded. It was also a way to keep track of thoughts, musings, speculations and hunches while engaging in the analysis.

**Analysis of Data**

The data were analysed both qualitatively and quantitatively. The students’ responses taken verbatim from the transcribed interviews were analysed using the Strauss and Corbin (1990) constant comparative method. Open coding was to identify pertinent words, verbs, adjectives or phrases from the students’ verbatim responses and tentative sub-categories were given by the researcher based on the appropriateness and logic of the description given. Similar themes that occurred in the students’ verbatim responses were highlighted and later cut and pasted together in a data matrix. This method allowed for categorisation and re-representation of the data as the interpretation developed. Initial coding was carried out by giving labels to the potentially relevant concepts in the transcribed transcripts.

In the final coding, a definition was given for the concept that clearly stated the qualities recognised initially in an unclear manner and when a new entry was classified under the relevant category. The TAT, students’ journals, classroom observation, observation during the interview and the researcher’s audit trail were similarly analysed for categories or patterns that emerged. These categories and definitions identified were then observed and matched to the list of skills stated in the TSTS framework.

**Findings and Discussion**

Students’ thinking prevailed as observed in the three phrases of the SGAR model (Maria, 2008) after the administration of the analogical task. A classroom observation showed the first traces of the TSTS components being used by the students in the Reception phase. They wrote short notes of the lesson, gathered and classified the information and sequenced the information according to priority. The following abbreviations are used to assist in the presentation of the findings and discussion: R represents the researcher, S the student and S1, S2, S3 represent different students.
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An audit trail of the classroom observation is shown below:

…….. once in a while students would **gather and classify** the important terms or sentences stated by the teacher and from the transparencies shown and transfer them to their notes.

*(Audit trail of classroom observation)*

When the students proceeded to seek an analogy for ‘translation’ as in the Interaction phrase, they underwent a process that challenged their minds to seek and rationalise the similarities and differences that existed within the analogy generated. The TSTS components observed during the analogy generation process is shown in the following interview excerpts and the students’ journals.

**R:** Why did you choose ‘mining ore’ as your analogy?
**S1:** The first picture that we get is from the lecture. So when the teacher is teaching, we **imagine** it….the teacher will explain the process, one by one, so we can **imagine** the thing happening in our heads.

**R:** Why did you choose a cash deposit machine as your analogy?
**S2:** That is how I thought of the cash deposit machine, the process of giving out the billing receipt which I assume as a polypeptide chain. There is a kind of **relationship**, that is why I choose ‘purchasing things at a supermarket’ as my analogy.

*(Interview excerpts)*

**S1:** Initially, I **imagine** the process of ‘translation’ whereby the ……. movement on the ‘mRNA’ strand.

**S2:** For me, I see it as a **relationship** between the function of the typewriter and typing an essay.

*(Students’ journals)*

The above findings showed that students are authentically engaged in the thinking process during the generation of analogies in the Interaction phase. This was observed by the words uttered by the students when interviewed such as, ‘to create’, ‘imagine’ and ‘form relationship’.

The TSTS skills of comparing and contrasting information (S2), to analyse, evaluate and rationalise before making decisions (S1, S3) was also identified from the following students’ interview excerpts and journal writing.
R: Why did you choose a train as your analogy?

S1: The mRNA is like the passenger, the ribosome...its function is to move from one codon to another, so it can be related to the journey of a train

S2: Because I see the Japanese restaurant, unlike other restaurants, the place where they serve the food is moving...like a train

(Interview Excerpts)

S3: To me, the bus seems more suitable because it functions like translation, stop, pick up passengers, move and then stop again, some passengers will go down and some will come up the bus. This is like tRNA carrying the amino acid, it will attach to the ribosome, leave the amino acid, go down.

(Student’s journal)

Besides the very distinct TSTS observed through the analogical task administered, several attributes such as stimuli, visual representation and social interaction seemed to become apparent and help initiate the process of analogical reasoning.

External stimuli such as key words (for example ‘process’, ‘elongation stage’ and such) and physical-structural features of the sub-concept of translation (such as the structure of ‘mRNA’, ‘tRNA’ and the ‘ribosome’) seemed to facilitate the access of the analogy and thus, is an important determinant in successful analogical reasoning. The key words seemed to enable the students to make connections or associate between the ‘target’ and ‘source’ concepts. This involves the creative skill of generating ideas, making relations and critical skills of comparing, contrasting, collecting and classifying as observed from the following student’s excerpt.

R: I see that you mentioned the word ‘move’ a couple of times in your explanation as in:

‘...saw a Japanese restaurant at the Mall, the food is moving...on a kind of conveyor belt...move,...then the waitress takes it and moves...bring it to the customer...well...a lot of movement going on here...’

R: Why is your emphasis on movement?

S: I think it is important.....because.....in the lecture...also...the teacher said that .....the ribosome will move, move, move... always move ahead......

(Interview Excerpt)
The above response from the student’s interview showed that the teacher uttered the word ‘move’ very frequently. Therefore, in one of the respondent’s analogy, she imagined the ‘movement’ of the ‘bullock-cart’ on the ‘road’ was like the ‘movement’ of the ‘ribosome’ along the ‘mRNA’ strand. Thus, her analogy of translation was a ‘bullock-cart’. The word ‘movement of the ribosome from one codon to another’ also triggered the thought of another respondent to relate her analogy to the ‘train moving from one station to another’.

This notion is supported by Vosniadou and Ortony (1989) whereby the salient features between the generated ‘source’ concepts and the concept of translation is responsible for the access or analogy generation. Similarly, key words which function as selective cues also seemed to assist in the recall or coding (observe, analyse, relate and make decisions) of the ‘source’ concept from long-term memory.

The learner’s personal goal, interest and experience are some of the internal stimuli that also facilitated analogical reasoning. The analogy generated will be dependent on the learners’ goal as to whether it is for understanding, retention, motivation and such. Similarly, the learner would probably seek for an analogy that interests them and which they have had experience with. This again engages TSTS such as making comparisons or connections, reasoning, and relating their experiences in the analogy with the ‘target’ concept. One example of this situation is found in the following excerpt:

*S: Eemmm….when I was in form 3, I like the subject Geography where I learn about the ‘mining system’ and choose it as my analogy. So sometimes…things from our everyday life that interest us can be applied here.*

(Interview Excerpt)

The interaction between the ‘target’ and ‘source’ concepts in self-generated analogical reasoning also involve recall and matching (to compare and contrast), and is shown to be influenced by visual representation such as diagrams, illustrations and charts found in the notes or texts. “Visual analogies” such as pictures, graphics and the like was shown to have a significant impact on problem solving according to Dreistadt (1969). For example, the visual allusion of a star had a significant impact of solving the problem related to the geometrical arrangement of trees (Dreistadt, 1969).
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This situation would again initiate students to be good problem solvers. The following students’ journals support the above statement.

R: What are you going to do when you cannot match them?
S: Maybe can add in this analogy.
R: What do you mean by add?
S: Think of what else that can be added. I will repair it back.
R: But I thought you said you wanted to change your analogy?
S: Ah….If like…..it cannot be repaired….then I will look for another analogy.
R: How are you going to repair it?
S: Like what …..That goes in…just add to it. Like the tRNA, its shape is like this, so if possible just add the curtains here, at the windows…if want to remember the tRNA. If it still cannot be matched, then look for another analogy.

(Students’ journals)

Another important finding of this study was the social interaction among the learners and their peer groups during the interaction phase of self-generated analogical reasoning. Even though, the students generated the analogies themselves, there seemed to be a need to interact among one another to perhaps discuss, exchange and debating ideas or notes and compare each other's analogy. This social interaction not only helps to build students’ self-confidence and self-esteem in generating the analogies but also encouraged several components of TSTS such as reflection and metacognition before making decisions. It is another important factor in the process of analogical reasoning, and therefore students should be allowed to work in groups to generate group analogies or individual analogies.

S1: Initially I don’t understand then, I looked at my friend to see if he has done it or not. He was also doubtful but he explained to me. After that I refer to the notes……understand a little and did the analogy.

S2 : Initially, I was unclear…..then I looked at my friends just in case I will get some ideas....

S3: After that saw my friends. They didn’t do the ‘train’ analogy so I continue to do the ‘commuter’ analogy.

(Students’ journals)
More TSTS components were observed when students tried to respond to the mismatches ('break down' of the analogy) in the Interaction phase. Three different strategies emerged from the students’ analogical reasoning to counteract the mismatches. Firstly, features of the ‘source’ concept will be modified slightly to accommodate the ‘target’ concept of translation, thus resulting in a modified ‘source’ concept. The process of modification of the ‘source’ concept is somewhat similar to Brown & Clement’s (1989) bridging analogy model whereby, ‘anchors’ or ‘anchoring concepts’ are sought to link between the ‘source’ and ‘target’ concepts.

R: How do you intend to respond to these mismatches?

S1: ….like just now, the large subunit is like the ‘coach’ of a train, so the P site is assumed to be half of the ‘coach’ while the A site the other half. Because the large subunit has 2 sites….so divide the ‘coach’ into 2 halves.

S2: ah….the next passenger gets on board…ah….the luggage….let’s say that some passengers has left their luggage…isn’t it? Ha…the peptide bond was not stated. They have entered….after that…ah…the ‘coach’ will move again.

S3: oh...yes, Once it has arrive to the end, may be the passenger left their luggage, then collect all the baggage…

(Students’ journals)

Secondly, a totally new analogy will be generated to substitute the existing analogy and this is also similar to Spiro, Feltovish, Coulson and Anderson’s (1989) multiple analogies model. The multiple or compound (as used in this study) analogies generated, seemed to complement the existing ‘source’ concept in an attempt to probably resolve the mismatches and also to use successive analogies that builds on one another. This perhaps helps facilitate the conceptualisation of the ‘target’ concept of translation. The following excerpts illustrate this situation.

R: What do you intend to do with the mismatches?

S: Change the analogy I think. I will do another analogy.

R: Why do you want to generate another analogy?

S: Because the analogy that I did is still not completed. To complete it, I will do another analogy based on the things that I did not match earlier. So that I can remember what….the things which I have left out…

(Excerpts)
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The third strategy was to ignore the mismatches but at the same time, the students seem to make a note of them as shown in the following excerpt.

R: So what do you think of the mismatches?

S: something that we cannot match…..when we did initially at that time, feels it’s a nuisance, to think of the similarities….but now….the ones that we cannot match (mismatches), it’s more relax as we take time to think of the similarities and differences isn’t it? So by thinking of the mismatches for a long time, we will remember them indirectly.

It could be argued that the implications of the first two strategies (modification of the initial analogy and generation of a new analogy) used by the students when a mismatch occurred between the concept of translation (‘target’ concept) and the ‘source’ concepts is that, the interaction between the two concepts seemed to move up to a higher level. This is where the students reflect, reorganise, rearrange and restructure as they recall other existing familiar concepts in order to elaborate, synthesise and create new matches. However, when students only took note of the mismatches and then decided to ignore it, it could be because the students chose not to make the effort. However, it could also mean that perhaps, these students may not realise that they did not have a clear conceptualisation of both the ‘target’ (concept of translation) and ‘source’ concepts and were satisfied with what they have described. This will warrant further study.

The Interaction phase in the SGAR is followed by the Emergent phase. In the Emergent phase the different types of analogies such as the single and compound analogies appear to stabilise. In other words, the initial ‘source’ concept or analogies that were thought of by the students in the Interaction phase, after having undergone changes, became more constant and stable during the Emergent phase. The complexity of the visual or verbal illustration in the presentation of the analogies seems to reflect the level of processing that could have occurred in the Interaction stage. In addition, the analogies generated also seem to expose the depth of experiences which the students have recalled from long-term memory, as they tried to match the analogy to the target concept, be it a functional match, a physical-structural match or a match of synonymous words or ideas. More single analogies were generated as compared to compound analogies. The compound analogies which stemmed from two or more single analogies, appeared to be the outcome of more complex processing of the mind during the Interaction phase, as students strived to solve the problem of mismatches.
Therefore, it can be postulated that the more complex analogies that emerged could be the result of more in-depth interaction between the ‘target’ (concept of translation) and ‘source’ concepts as students made the effort to overcome mismatches. The mismatches seemed to encourage the students to engage in metacognition, be critical and creative, to remember, speculate, reflect, become aware of, to modify, to create and evaluate before they make the final decision about their analogies. This continuous process of matching and mismatching (between features of the ‘source’ concept and the sub-concepts of translation) that took place in the Interaction phase probably could enable the students to understand in-depth the ‘target’ concept and thus, better retain this abstract concept in their mind for future use.

**Conclusion**

The most important TSTS process using an analogical task is indicated in the SGAR model (Maria, 2004) where the process to seek matches and attend to the mismatches (‘break down’ of the analogy) occurs. This is crucial because, it involves higher level thinking processes among the students. The Interaction phase of the SGAR model can be assumed to incorporate the processes of organisation and elaboration as in the Information Processing Theory of Atkinson and Shiffrin (1968), the equilibration stage of Piaget’s (1929) cognitive theory and the process of schema tuning and schema creation in Rumelhart and Norman’s (1981) theory of learning. The mismatches seemed to induce cognitive conflict to the encoding of new information (abstract science concept being learnt) in long-term memory. The process of attending to the mismatches apparently appears to play an important and crucial role in the conceptualisation of the abstract science concept since it involves securing a balance between the schema of the learnt abstract concept and the already existing schema in memory. As such, students and teachers should be advised to acknowledge the mismatches, as it can be argued that this is where the process of higher order thinking (HOTS) takes place to assist in the understanding and retention of the abstract science concept.

The SGAR model emerged from the perspective of the learner using an analogical task. It could be used as two prongs, (i) to guide the learner, the teacher and also the textbook authors in generating analogies, and (ii) to incorporating thinking skills during the process. What is probably an advantage of this model is that, it was designed to accommodate the needs
of the learner as an information receiver in the learning process. In doing so, the students develop thinking subconsciously which they probably might not engage in if asked to think consciously in a lesson. Once clearly explained and after practices with analogies, students could be encouraged to practice self-regulated learning for other abstract science concepts. Thus, it can be observed that the analogical task could possibly play a dual role of facilitating both the teaching and learning process and also inculcating creative and critical TSTS as envisioned in the Malaysian science curriculum.

References


**Author:**

Maria Salih, Faculty of Science and Technology, Sultan Idris University of Education Malaysia; email: maria@fst.upsi.edu.my