Journal of Science and Mathematics
Education in Southeast Asia
2008, Vol. 31 No 2, 164-177

A Proposed Model of Self-Generated Analogical Reasoning for the Concept of Translation in Protein Synthesis

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This paper explored and described the analogical reasoning occurring in the minds of different science achievement groups for the concept of translation in protein synthesis."What is the process of self-generated analogical reasoning?", "What types of matching was involved?" and "What are the consequences of the matching processes?" were some of the research questions asked. The data was collected in multiple forms using the Translation Analogy Task (TAT), structured interviews, students' journals, researcher's observations (classroom and during interviews) and audit trail. 99 participants from a Matriculation College in the vicinity of Kuala Lumpur, Malaysia participated in this study. The participants were categorised as low, average and high achievers using the Translation Test (TT) results. The findings were put forth in the form of a model of Self-Generated Analogical Reasoning (SGAR).

Key words: Analogy; Analogical reasoning; Analogy task; Abstract science concept, Model; Science achievement

Introduction

The main purpose of this study was to explore and describe the analogical reasoning occurring in the minds of different biology achievement groups for the concept of translation in protein synthesis. In order to achieve this objective, data was collected in multiple forms from 99 students namely by using the Translation Analogy Task (TAT), structured interviews, students' journals, researcher's classroom observations and audit trail. The students were from a Matriculation College in the vicinity of Kuala Lumpur. As described in the methodology, all the students were Malay and they were categorised as low, average and high achievers in Biology by using the translation test results. As such, the model that will be put forward may only apply to this particular sample that participated in the study and cannot be generalised, unless a similar sample with similar environmental elements is used. The model of self-generated analogical reasoning was proposed based on findings from this study. The findings were then related to relevant theories that supported the notion of the data obtained.

Proposed Model of Self Generated Analogical Reasoning

There are various process models of analogical reasoning used as strategies in the teaching and learning of science. These models were developed through research conducted by many researchers. However, most of the models were based on the teaching of analogies and thus constructed for the use of teachers. One of the earliest models was the General Model of Analogy Teaching (GMAT) proposed by Hassan Hussein Zeitoun (1984). Another most commonly used model for teaching analogies was the Teaching-with-Analogy model proposed by Glynn (1989). Not many analogical reasoning models were constructed from the learner's perspective except for Wong's (1993a and 1993b) student-generated analogies model. Wong's (1993a and 1993b) model, however, was based on an incomplete or poorly organised background knowledge that was not domain specific and also of the problem solving type. The model focused on the change in students' understanding of a given scientific phenomenon (through their explanations) when they were asked to generate, evaluate and modify their own analogies. Other existing analogical reasoning model such as LISA (Learning and Inference with Schemas and Analogies) aims to represent the role of analogies in thinking within a neural-network (Hummel & Holyoak, 2005). It is sometimes referred to as the neural-network model of relational thought or neurocomputational Model of analogical reasoning (Morrison etal., 2004). Subsequently, work in philosophy of science suggests that analogical inference is also guided by causal models of the source and target (Lee & Holyoak, 2007). The author alternatively proposes another model which is for a domain specific knowledge, in relation to the process of self-generated analogical reasoning of the science students and based on the findings of this study. Before presenting the actual model proper, the framework for the model will first be presented and discussed.

Framework for Model

Since the postulation of the self-generated analogical reasoning model is data driven, a framework based on the findings of this research will be discussed first, followed by a detailed description of the model. The following points will be covered in this framework.

1. Definition of the Analogy
2. Self-Generated Analogical Reasoning
3. Attributes related to Self-Generated Analogical Reasoning
4. Outcomes of Self-Generated Analogical Reasoning

Definition of the Analogy

The definition of an analogy in this study is based on four components namely, 'target', 'source', 'match' and 'mismatch'. 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 task (Gick and Holyoak, 1980; Holyoak, 2005). Translation is the 'target' concept in this study. The 'source' concept is a familiar visualisable material that is obtained from the surrounding or from a situation in the environment. It is used to facilitate the learning of the 'target' concept. It must be noted that, in this study, the 'source' also represents the analogy and vice-versa. The term 'match' refers to the similarities shared between the corresponding features of the 'source' concept and the sub concepts of the 'target' concept. The term 'mismatch' is used to indicate any form of differences or dissimilarities between the features of the 'source' concept and the sub concepts of the 'target' concept. This is also the 'break-down' of the analogies. Thus, the definition of an analogy in this model is a concrete and visualisable representation of the matches and mismatches between the 'source' and 'target' concepts.

Self-Generated Analogical Reasoning

The whole idea of analogy and analogy generation is probably a new experience and encountered by these sample of students for the first time. As such, the whole process of self-generated analogical reasoning seemed to involve the students' emotions. This was the first finding observed when the students were asked to generate analogies of translation during the TAT. All the students experienced mixed feelings of anxiety and excitement which was portrayed on their face by their behaviour and through the responses given in the interviews and written journals. Two different types of emotions were felt by the students of all three achievement levels. Firstly, they seemed to be worried about the task because some of them were still vague about analogy and the concept of translation. Others were afraid that they might not be able to generate the analogies intended. Then, there is the fear of being not able to generate a suitable and correct analogy. While these feelings were experienced by some students, another group of students seemed to find analogy generation fun and interesting. They enjoyed the challenge of retrieving the 'source' concept and then seeking the matches because it gave them the opportunity to be creative and innovative in generating the analogies. Some found it interesting and motivating to learn the different abstract concept. Others thought that the process of analogy generation made retention of the concept learnt much easier. When the students finally got down to doing the TAT, these emotions slowly resided.

A kind of stimulation seemed to overpower the emotions soon after. The external stimulation were the key words such as 'movement', 'process', 'place' and such. These words were obtained from the biology module that was used in their lectures on protein synthesis. The word 'move' was again emphasised by the teacher during a lecture on translation. The physical structure appeared to be another stimulation that triggered the students to get access to the 'source' concept. The structures of the sub-concepts of translation such as the 'ribosome', the 'mRNA' and the 'tRNA seemed to have a strong impact on the students. Again these structures were seen from the notes and diagrams on translation in the biology module. The internal stimulation also seemed to influence the thinking and retrieval of the 'source' concept. These stimuli include the students' personal goal of generating the analogy, their personal interest and experiences. Thus, they seemed to be automatically triggered to look for something that they like and enjoy doing, and places that they frequented. Some thought of familiar situations that they had experienced. Others fell back to what actually was the purpose of their task.

Therefore, it could be assumed that the initial step in the process of self-generated analogical reasoning is the retrieval of a 'source' concept for the analogy. Based on the findings of this study, the access process is initiated by both internal and external stimuli. The external stimuli, as described earlier are instances from the environment that include both sensory and motor stimulus. Similarly, the internal or intrinsic stimulus that came from within the student's themselves were personal interest, experience and objectives. With this initial stimulus, the 'source' concept was thought of and identified. Once stimulated, the students seemed to try and visualise or imagine the 'source' and the 'target' concepts. The visualisation was performed by first recalling the similarities between the 'source' and 'target' concepts before proceeding to the matching process. The recall process was initiated by referring to drawings, diagrams and illustrations in the notes and text and also by referring to peers. It is here that the students tend to draw diagrams of the visualised 'source' concept or translation or both.

It seemed difficult to predict whether the process of recall happens before the stimulation stage, after or simultaneously throughout the process of analogical reasoning. Irrespective of when it occurred, the recall process is important and seemed to be part of the process of analogical reasoning.

The outcome of the emotions, initial stimuli and the process of recall are the generated 'source' concepts or analogies of the students. With the generation of these analogies, the process of matching between the features of the 'source' concept and the sub concepts of translation takes place.

The process of matching starts by looking for matches or similarities between the two concepts. The students' emotions seemed to be activated once again during the process of matching. It was here that the students were worried whether their matches were correct, logical or suitable. In the process of doing this, students may probably encounter the mismatches or dissimilarities. The finding from this study seemed to show that students probably responded to these mismatches via several different strategies. Firstly, they may probably try to overcome the mismatches by making some modifications to the existing features of the 'source' concept so as to match this sub-concept of translation. This is the modification of the existing analogy. Secondly, students would probably generate a totally new analogy to supplement or replace the existing analogy. This is done by creating an entirely new analogy and going through the process of analogical reasoning again. Alternatively, students would probably ignore the mismatches and only concentrate on the matches obtained. The process of seeking matches and confronting mismatches is a continuous back and forth process that involves comparing and contrasting between the two concepts. The findings also showed that the outcome of responding to the mismatches resulted in the acquisition of several important mental skills such as cognitive, meta-cognitive and creative and critical thinking skills. It also seemed to show that, by responding to these mismatches the understanding and retention of the abstract science learnt was probably facilitated.

Possible Variables Related to Self-Generated Analogical Reasoning

The findings from this study seemed to show some possible variables that are related to the self-generated analogical reasoning. These variables are:

1. Emotions
2. External and internal stimuli
3. Visual representation
4. Social interaction
5. Types and complexity of analogy
6. Types of matches and mismatches
7. Responses to mismatches

The Self-Generated Analogical Reasoning Model is shown in Figure 1. A detailed discussion of the above respective variables in relation to the model will now be discussed.

Self-Generated Analogical Reasoning Model

The self-generated analogical reasoning model as shown in Figure 1 proceeds in the following three phases namely, 1. Reception phase, 2. Interaction phase and 3. Emergent phase.

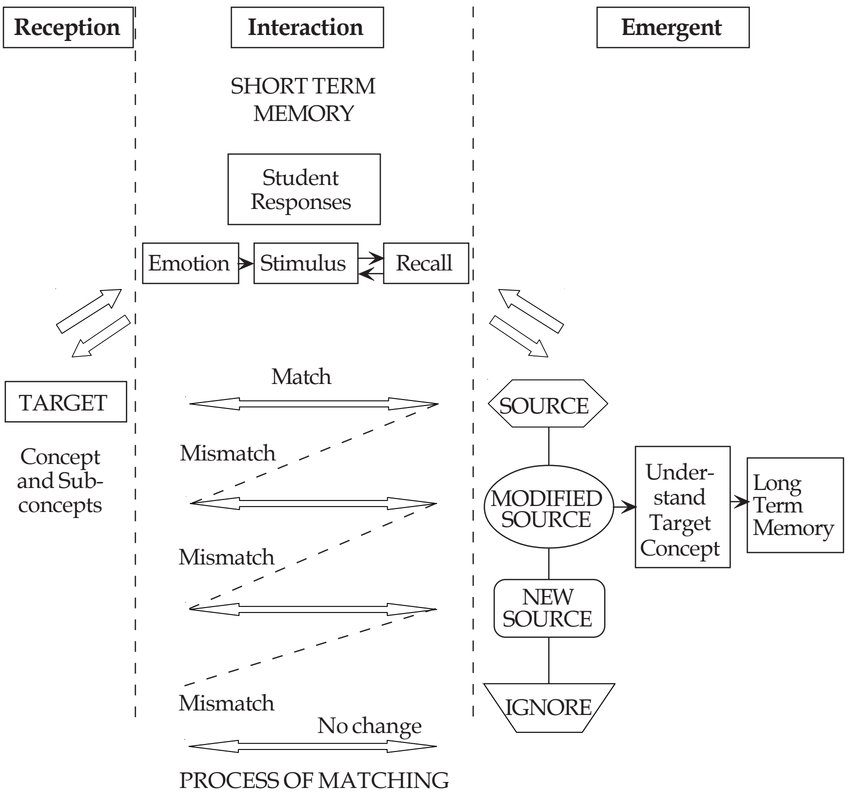

Figure 1. Self-Generated Analogical Reasoning (SGAR) Model (Maria, 2004).

1. *Reception Phase*

In this phase of the model, 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 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.

2. Interaction Phase

The interaction phase includes the emotions, stimuli, visual representation and social interaction variables. In self-generated analogical reasoning, the learner's emotions should be considered and taken into account. This is important because the learners' emotions probably influence the process of analogical reasoning. The negative emotions would also probably discouraged and de-motivate the learner from using and generating analogies. Thus, a positive and stimulating mindset as well as the learning environment should be cultivated to booze up the learner's positive emotions towards analogy and analogy generation.

The stimuli also seemed to be another important variable in self-generated analogical reasoning. The key words and physical-structural features of the 'target' concept seemed to facilitate the access of the analogy and thus, an important determinant in the successful analogical reasoning. This notion is supported by Vosniadou and Ortony (1989) whereby the salient features between the 'source' and 'target' concepts is responsible for the access or analogy generation. Similarly, key words that functioned as selective cues also assisted in the recall or coding of the 'source' concept from long term memory. The learner's personal goal, interest and experience are some of the internal stimuli that probably facilitate the access of the analogy. 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 interest them and which they have had experience with. Therefore, there seem to be five stimulation variables that are related to self-generated analogical reasoning.

The process of recall of the 'target' and 'source' concepts in analogical reasoning seemed to be influenced by the visual representation of both these concepts as compared to the written representation (Figure 2). This finding was supported by Donelly (1990) and Schwartz (1993) who agreed that visual representation that accompanies the verbal analogy is important to enhance the learners' understanding of the 'target' concept. Therefore, there ought to be some kind of visual representation of either the analogy, the 'target' or both concepts in order to assist and ease the access and process of matching in analogical reasoning. The process of recall was also facilitated by referring to any visual written materials such as diagrams, illustrations and charts found in the notes or texts.

Another important variable obtained from the findings of this study was social interaction among the learners' and their peer groups during the process phase of 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 ideas or notes and compare each other's analogy. The social interaction factors probably help to ease the student's negative emotions and build up their self confidence and self-esteem in generating the analogies. Thus, it is another important factor that should not be neglected in the process of analogical reasoning.

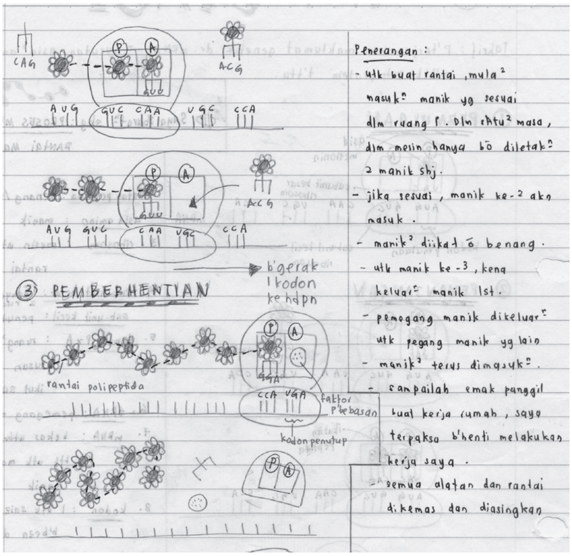

Figure 2. Representation of 'bead making' analogy of 'translation in protein synthesis' (Maria, 2004).

3. *Emergent Phase*

The types and complexity of the analogies, types of matches and mismatches, responses to the mismatches and the skills acquired are some of the possible identifiable variables in self-generated analogical reasoning. The outcome of the interaction phase in analogical reasoning gave rise to the different types of analogies such as the single and compound analogies. The presentation of the analogies and the elaboration of the process of matching determine the complexity of the analogies generated. This includes the visual or verbal illustration in the presentation and the personal involvement of the learner in the analogy generated.

Another vital part of the outcome phase of self-generated analogical reasoning is the process of matching. The process of matching between features of the 'source' and 'target' concepts is a continuous process of seeking for matches and mismatches (Table 1). There seemed to be four different types of matches that is shared by the 'source' and 'target' concepts namely, the functional, physical-structural, synonymous ideas and words similarity. Similarly, for the mismatches, the functional and physical-structural differences or dissimilarity are found to be important. Therefore, in the process of matching, the factors influencing the self-generation of an analogy are the functional, physical-structural, synonymous words similarity for the matches and the functional and physical-structural dissimilarity for the mismatches.

The response to the mismatches is another important variable in the emergent phase. It seemed that there are three different strategies taken to overcome the mismatches during the process of matching. Firstly, features of the 'source' concept would probably be modified slightly to accommodate the 'target' concept. This will result in a modified 'source' concept. The process of modification of the 'source' concept is somewhat similar to Brown and Clement's (1989) bridging analogy model whereby, 'anchors' or 'anchoring concepts' are sought to link between the 'source' and 'target' concepts. Secondly, a totally new analogy would probably be generated to substantiate the existing analogy and this, perhaps, is also similar to the multiple analogies model (Spiro, Feltovish, Coulson and Anderson, 1989). 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 would probably facilitate the conceptualisation of the 'target' concept. The third possible strategy was to ignore the mismatches but at the same time, making a note of them so that the learners' are aware and can remember these mismatches.

Another important variable in the emergent phase of self-generated analogical reasoning was probably the understanding and retention of the learnt 'target' concept. This was probably possible by responding to the mismatches encountered which seemed to result in encouraging the students to reflect back on their matches and their analogies and rethink their arguments more analogically and critically. The process of seeking for the appropriate physical-structural and functional matches are likely to initiate the students to think in this manner as compared to those students who were not aware of the mismatches or who did not acknowledge the mismatches. This was probably one good reason as to why the physical-structural and functional similarity was said to be equally important in the process of analogical reasoning. The process of matching seemed to encourage the students in the cognitive, metacognitive and critical and creative processes of 'remembering', 'initiating', 'speculating', 'reflection', 'awareness', manipulation', 'modification', creation', 'evaluation' and such before they made the final decision. This continuous process of matching (between features of the 'source' concept and the sub concepts of translation) probably enabled the students to deeply understand the 'target' concept and thus, retain in their mind for future retrieval.

Table 1
Analogical Matching of 'Bead Making' to 'Translation in Protein Synthesis' (Maria, 2004)

Matches (Similarities)	
'Bead Making' (Source)	Translation (Target)
Thread	Peptide chain
Beads	Amino acids
Bead making machine	Ribosome
Bead holder	tRNA
Multi pattern container	mRNA
Twizer with 2 compartments	Large ribosomal sub-unit
Twizer cover	Small ribosomal sub-unit
Mismatches (Differences)	
Twizer has no compartments	

Conclusion

Most analogical reasoning models have focused on the teaching of analogies as in the General Model of Analogy Teaching (GMAT) (Hassan Hussein Zeitoun, 1984) and the Teaching-With-Analogy Model (Glynn, 1989). Basically, these models were used by the teachers and textbook authors to come up with an analogy in the teaching and learning of science concepts. As such, the analogies generated were probably to the advantage of the teachers or textbook authors but not to the learners themselves. This was because of the differences in prior knowledge and learning experiences between the teachers and the learners. Other models such as the bridging analogy model and the multiple analogies model were postulated based on the shortcomings of some aspects during the analogical reasoning process. For example, in the bridging analogy model, the set of connectors or anchors are necessary to assist in the matching and to get a good understanding of the 'target' concept. In the multiple analogies model, several analogies were used to facilitate the understanding of the 'target' concept. Basically, all the models are teacher-generated analogies, textbook analogies and constructed based on the perspective of the teachers or textbook writers. Some of these models probably stand by themselves without being supported by any existing theories such as the GMAT model (Duit, 1991).

This is a self-generated analogical reasoning model constructed from the perspective of the learner and is probably the best prototype to explain the process. Perhaps it could be used as a guideline for the learner, the teacher and also the textbook authors to generate analogies. The advantage of this model is that it was designed to accommodate the needs of the learner as an information receiver in the learning process and the other respective individuals as mentioned above in the teaching process. Thus, this model seemed to play a dual role of facilitating both the teaching and learning process. It also seemed to represent all the other earlier analogy models such as the 'Bridging Analogy' model and the 'Teaching-With-Analogy' model because it seemed to incorporate the ideas of all the other existing models. The outcome of the matching process itself probably enables the learners to seek the appropriate analogies as anchors to one another. Similarly, the outcome of the compound analogies probably showed the use of several analogies to build on each other. This is one initial research in the local context that tends to exploit analogical reasoning during the generation of analogies from the neuroscience perspective using a qualitative approach. More extensive research using large samples and multi methods need to be conducted to verify the significance of this model and its relation with existing models as in the LISA project (Holyoak & Morrison, 2005) or the causal models of analogical inference (Lee & Holyoak, 2008).

References

Brown, D. E. & Clement, J. (1989). Overcoming misconceptions via analogical reasoning: Abstract transfer versus explanatory model construction. *Instructional Science, 18,* 237–261.

Donnelly, C. (1990). Does analogy enhance comprehension of scientific concepts? (Doctoral dissertation, New School for Social research, 1990). *Dissertation Abstracts International, 51*, 4632–B.

Duit, R. (1991). On the role of analogies and metaphors in learning science. *Science Education, 75(6),* 649–672.

Gick, M. L. & Holyoak, K. J. (1980). Analogical problem solving. *Cognitive Psychology, 12,* 306–355.

Glynn, S. M. (1989). The teaching with analogies (TWA) model: Explaining concepts in expository text. In K.D. Muth (Ed.), *Children's comprehension of text: Research into practice*, *(pp. 185-204)*. Mahwah, NJ: Erlbaum.

Hassan Hussein Zeitoun (1984). The relationship between abstract concept achievement and prior knowledge, formal reasoning ability and gender. *International Journal of Science Education, 11 (2)*, 227-234.

Holyoak, K. J. (2005). Analogy. In K. J. Holyoak & R. G. Morrison (Eds.), *The Cambridge Handbook of Thinking and Reasoning (pp. 117-142).* Cambridge, UK: Cambridge University Press.

Holyoak, K. J., & Morrison, R. G. (2005). Thinking and reasoning: A reader's guide. In K. J. Holyoak & R. G. Morrison (Eds.), *The Cambridge Handbook of Thinking and Reasoning* (pp.1-9). Cambridge, UK: Cambridge University Press.

Hummel, J. E., & Holyoak, K. J. (2005). Relational reasoningin a neurally-plausible cognitive architecture: An overview of the LISA project. Current Directions in *Cognitive Science, 14,* 153-157.

Lee, H. S., & Holyoak, K. J. (2007). Causal models guide analogical inference. In D. S. McNamara & G. Trafton (Eds.), *Proceedings of the Twenty-ninth Annual Conference of the Cognitive Science Society (pp.1205-1210)*. Austin, TX: Cognitive Science Society.

Lee, H. S. & Holyoak, K. J. (2008). The Role of Causal Models in Analogical Inference, *Journal of Experimental Psychology:Learning, Memory and Cognition, Vol. 34, No. 5,* 1111-1122

Maria, S. (2004). *Science students self-generated analogical reasoning of the concept of translation in protein synthesis.* Unpublished PhD Thesis, University of Malaya.

Morrison, R. G., Krawczyk, D. C., Holyoak, K. J., Hummel, J. E., Chow, T. W., Miller, B. L. & Knowlton, B. J. (2004). A neurocomputational model of analogical reasoning and its breakdown in Frontotemporal Lobar Degeneration. *Journal of Cognitive Neuroscience, 16,* 260-271.

Reigeluth, C. M. (1980). *Meaningfulness and instruction: relating what is being learned to what a student knows.* Working Paper No. 1, Instructional Design Development and Evaluation Program, School of Education, Syracuse University, New York. (Submitted to Instructional Science in 1982).

Schwartz, D. L. (1993). The construction and analogical transfer of symbolic visualizations. *Journal of Research In Science Teaching, 30* (10*),* 1309–1325.

Spiro, R. J., Feltovich, P. J., Coulson, R. L., & Anderson, D. K. (1989). Multiple analogies for complex concepts: antidotes for analogy-induced misconception in advanced knowledge acquisition. In S. Vosniadou & A. Ortony (Eds.), *Similarity and analogical reasoning* (pp. 498-531). Cambridge MA: Cambridge University Press.

Vosniadou, S. & Ortony, A. (1989). Similarity and analogical reasoning: A synthesis. In S. Vosniadou & A. Ortony (Eds.). *Similarity and Analogical Reasoning.* Cambridge MA: Cambridge University Press.

Weller, A. (1970). The role of analogy in teaching science. *Journal of Research in Science Teaching, 7,* 113–119.

Wong, E. D. (1993a). Self-generated analogies as a tool for constructing and evaluating explanations of scientific phenomena. *Journal of Research In Science Teaching, 30,* 367–380.

Wong, E. D. (1993b) Understanding the generative capacity of analogies as a tool for explanation. *Journal of Research In Science Teaching, 30*(10*),*1259–1272.

Note:

This article originated as a paper presented at the 13th International Conference on Thinking, Norrkoping, Sweden, 17- 21 June, 2007.

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