Modern Applied Science; Vol. 11, No. 1; 2017
ISSN 1913-1844 E-ISSN 1913-1852
Published by Canadian Center of Science and Education

Improving Teaching and Learning Outcomes – A Novel Cognitive Science Approach

Stanislaw Paul Maj[1]

[1] Associate Dean (Research), Engineering Institute of Technology, Western Australia

Correspondence: Stanislaw Paul Maj, Associate Dean (Research), Engineering Institute of Technology, 1031 Wellington St., West Perth, 6005. Western Australia. Tel: 1300-138-522. E-mail: paulm@eit.edu.au

Received: August 12, 2016 Accepted: October 8, 2016 Online Published: December 19, 2016

doi:10.5539/mas.v11n1p264 URL: http://dx.doi.org/10.5539/mas.v11n1p264

Abstract

Three principle approaches to education are behaviorism, constructivism and cognitive science. However beyond that there are a wide and diverse range of methods such as outcomes based education, problem based learning etc. All these approaches and methods have their associated advantages and disadvantages. The effectiveness of the educational process is measured by a learning taxonomy such as Bloom or Structure of the Observed Learning Outcome (SOLO). The paper links the cognitive science approach with the SOLO taxonomy as the basis of a quantitative approach to measuring cognitive load which is a measure of mental effort. This can then be used as the basis of curriculum design in order to optimize learning outcomes.

Keywords: SOLO taxonomy, pedagogy, cognitive science

1. Introduction

1.1 Teaching and Learning theories

In order to effectively write course materials and teach it is essential to have an understanding of how students learn. Learning theories can be organized into three main groups: behaviorism, constructivism and cognitive science. However other classification groupings are possible. The basis of behaviorism is operant conditioning. According to Skinner the desired behavior is encouraged and reinforced by operant conditioning (Skinner, 1948). Skinner identified four types of operant conditioning: negative and positive reinforcement, punishment and extinction. Hence Behaviorism emphasizes the importance of practice and is the basis of programmed instruction in which new material is provided in a set of discrete segments called frames each with an associated question or set of questions (Dick, 1990). The basis of Constructivism is that each student has a different perception and ‘constructs’ new knowledge based on their existing knowledge. There are two main approaches to Constructivism, namely psychological (aka individual) and social. Psychological constructivism is primarily concerned with individual learners (Piaget, 1952). Piaget defined the four processes of: assimilation, accommodation, disequilibrium and equilibration as the basis of learning. By contrast the social constructivist approach places learning in the broader context of social interactions (Vygotsky, 1978). The cognitive science approach is based on how people process information based on the interaction between short and long term memory and the development of mental ‘maps’ called schemata (Rumelhard, 1980). Each theory has advantages and disadvantages but the strength of the cognitive science approach is that it is possible to employ a quantitative approach (S. P. Maj, Veal, D., 2010). Maj demonstrated that it was possible to quantitatively evaluate course materials and also optimize the learning sequence. However this work did not employ a learning taxonomy.

1.2 Teaching and Learning taxonomies

The efficacy of teaching and learning is measured by a learning taxonomy such as Bloom (Bloom, Engelhart, Furst, Hill, & Krathwohl, 1956). Bloom identified taxonomies for the cognitive, affective and psychomotor domains. However this paper is concerned only with the cognitive domain. The cognitive taxonomy defines six major groups ranging from low order learning to high order learning namely: knowledge, comprehension, application, analysis, synthesis and evaluation. To facilitate use of this taxonomy action verbs are used. For example knowledge sample verbs could be: list, name and label. By contrast the evaluation action verbs could be: critique, evaluate etc. However according to the Assessment for Teaching and Learning Team at the University of Auckland, ‘Despite the popularity of Bloom cognitive taxonomy, there is little support for the use of it in organizing instruction, curriculum, or assessment' (Team, 2004). It has been argued that the categories identified by Bloom do not represent a hierarchical ordered set (McMillan, 2001). In order to address this concern the taxonomy has been modified (Krathwohl, 2002). Despite this, it has been argued that problems exist with this type of learning taxonomy (Hattie, 1998). The Structure of the Observed Learning Outcome (SOLO) taxonomy defines levels of learning from low order to high order, namely pre-structural, uni-structural, multi-structural, relational and extended abstract (Biggs & Collis, 1989). Uni-structural and multi-structural learning are defined as surface learning in which the student has not identified links or relationships between learnt items. By contrast relational and extended abstract are classified as deep learning in which aspects of learning are integrated so that the whole corpus of understanding has a coherent structure and meaning. There are four methods by which this hierarchy of learning can increase in complexity: capacity, relationship, structure, consistency & closure (Team, 2004). For structure the hierarchy of learning is progression for example from multi-structural in which the learner links items together and relational where the learner identifies the underlying conceptual structure. For the hierarchy of learning in capacity the low order levels require the student to remember singular items whereas with high order learning the student must think not only about items but also how they are related. SOLO has been applied to a wide range of disciplines ranging from the arts (Biggs & Collis, 1989), to the sciences (Collis, 1986).

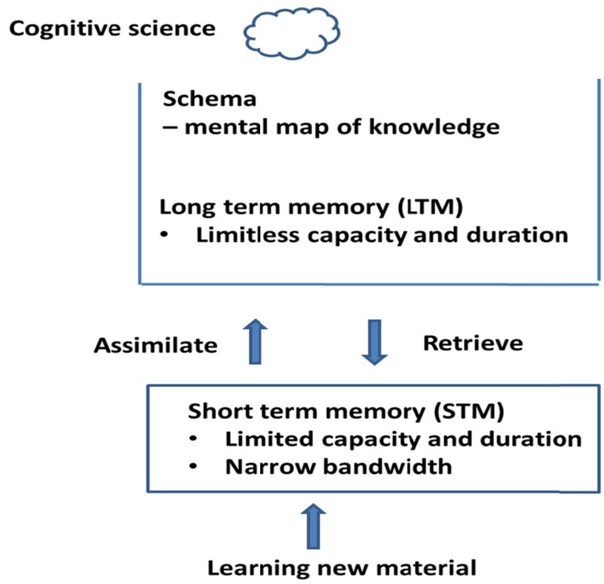

Figure 1. Cognitive science – short and long term memory

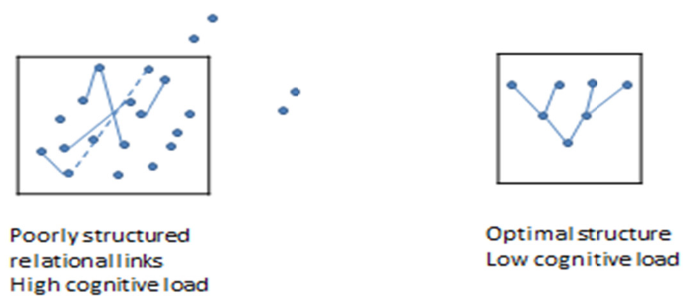

Figure 2. Poorly structured high order relational knowledge

2. Cognitive Science

2.1 Linking Cognitive Science with SOLO taxonomy

The cognitive science approach recognizes the outcomes of learning as schemata resident in long term memory. In the process of learning new knowledge passes through short term memory which is of limited capacity and duration. The schema, relevant to the subject being studied, is resident in long term memory and during the process of learning it is retrieved and the new knowledge is assimilated thereby modifying the schema (Figure 1). In effect learning is the iterative process of retrieve and assimilate. The advantage of this approach to learning is that it explicitly recognizes the roles of the two types of memory – long term and short term. This is important because this model clearly identifies the intrinsic limitations of short term memory which must inform teaching and learning principles and practices. Structural knowledge (knowing why) links declarative and procedural knowledge (Diekhoff, 1983). Hence structural knowledge, also called cognitive or internal knowledge, is represented by the patterns in schemata. The underlying principles are based on data similarities also referred to as semantic proximities (Nagy, 1984). As such the objective is a quantifiable measure of closeness (Keppens, 2008). There exist a wide range of theories and associated methods associated with structural knowledge but they share the common goal of controlling the complexity of the relationships that exist in structural knowledge (Jonassen, 1993). Methods include: hierarchical structured relationships (Meyer, 1985); slots and frames (Minsky, 1975); elaboration theory (Reigeluth, 1979); special semantic maps (Larkin, 1987) to name but a few. Methods such as these are designed to identify and improve poorly designed content. The quality of the content may be measured using the SOLO taxonomy. Poorly designed material may be represented by data items with few or poorly structured relational links (figure 2). In this figure each node represents an item of knowledge such a hardware address is OSI layer 2 address; an IP address is an OSI layer 3 address. However these isolated nodes represent rote or low order learning. They have no cognitive links and represent isolated items of information. Only when these nodes are linked to other nodes is there multi-structural leaning. For example the Address Resolution Protocol (ARP) maps hardware and IP addresses. This would be represented diagrammatically by a link between these nodes. Higher order learning therefore can be represented by an extensive pattern of inter-related nodes linked in a meaning full manner that represents understanding. In effect it is possible to traverse the nodes to answer questions like 'why do hardware and IP addresses have to be mapped?' Links in conjunction with nodes represent reasons or explanations. However it possible for the cognitive map to be poorly structured with missing cognitive links and poorly structured. In this case this represents a less than optimal learning structure with a high cognitive load: in effect students are left to create their own cognitive links which could well be incomplete, inconsistent or incorrect. However as an isolated node this would be considered rote or low order learning. There are no cognitive links; it is an isolated piece of information. Only when this node is linked to other nodes is there multi-structural learning. In the case of ARP this is a protocol that maps IP addresses to hardware addresses. Clearly this represents high order relational knowledge because of the presence of relational links, but it is poorly structured and hence represents a less than optimal learning structure as such this represents a high cognitive load, furthermore the student is left to create their own cognitive links which are likely to be incomplete, inconsistent and incorrect. Ideally content should have an optimal relational learning structure with minimal cognitive load (figure2).

2.2 Minimizing cognitive load – a quantitative method

There are a wide range of methods for organizing learning structure such as: pattern and spider maps (Hanf, 1971); semantic maps (Fisher, 1990); cross classification tables (Frase, 1969). However according to Maj 'All the techniques and methods could be used to represent and hence define explicit structured knowledge for routing protocols. Most were easy to learn and use supporting for some methods. However none of the methods provided rigorous methods for defining concepts and characters. Furthermore none of the methods provided a rigorous, quantifiable mechanism for determining and calculating structured relationships' (S. P. Maj, Veal, D., 2010). Maj proposed a new quantitative method, based on a parsimony algorithm that could define a logical learning sequence with the minimum cognitive load.

3. Method – linking cognitive load with SOLO taxonomy

3.1 Cladistics

Cladistics is a method of classification in biological systems that group taxa (named group) hierarchically into discrete sets and subsets. The aim is to hypothesize relationships that may be expressed as a branching diagram (cladogram). Taxa are defined by common characteristics that may be: plesiomorphic (primitive and more inclusive) or apomorphic (advanced and less inclusive). The problem is to obtain the optimal cladogram given there can be a large number of characters that can be organized in many different ways which is computationally intensive. The Phylogenetic Analysis Using Parsimony (PAUP) was designed for biological systems in order to arrange organisms into a hierarch in the simplest and most parsimonious, quantifiable manner and runs on a standard PC. The Cisco Network Academy Program (CNAP) is recognized as a global exemplar of best practices in IT education. Maj applied PAUP to a CNAP learning topic (routing) and found that it was a less than optimal learning sequence. Using PAUP the optimal learning sequence for this topic as map and proven to be optimal

(S. P. Maj, Veal, D., 2010).

3.2 Optimal Learning Sequence

If course material was organized according to this sequence it would represent the most efficient learning path and hence the optimal learning sequence with the minimal cognitive load transitioning from low order to high order learning (Figure 3). Initial learning is based on items of information that is progressively linked. The course material, defined by the PAUP algorithm, defines what should be taught and in what sequence. In this PAUP defined sequence there are no large cognitive loads because the sequence represents the easiest way to learn the topic. Furthermore there are no isolated nodes.

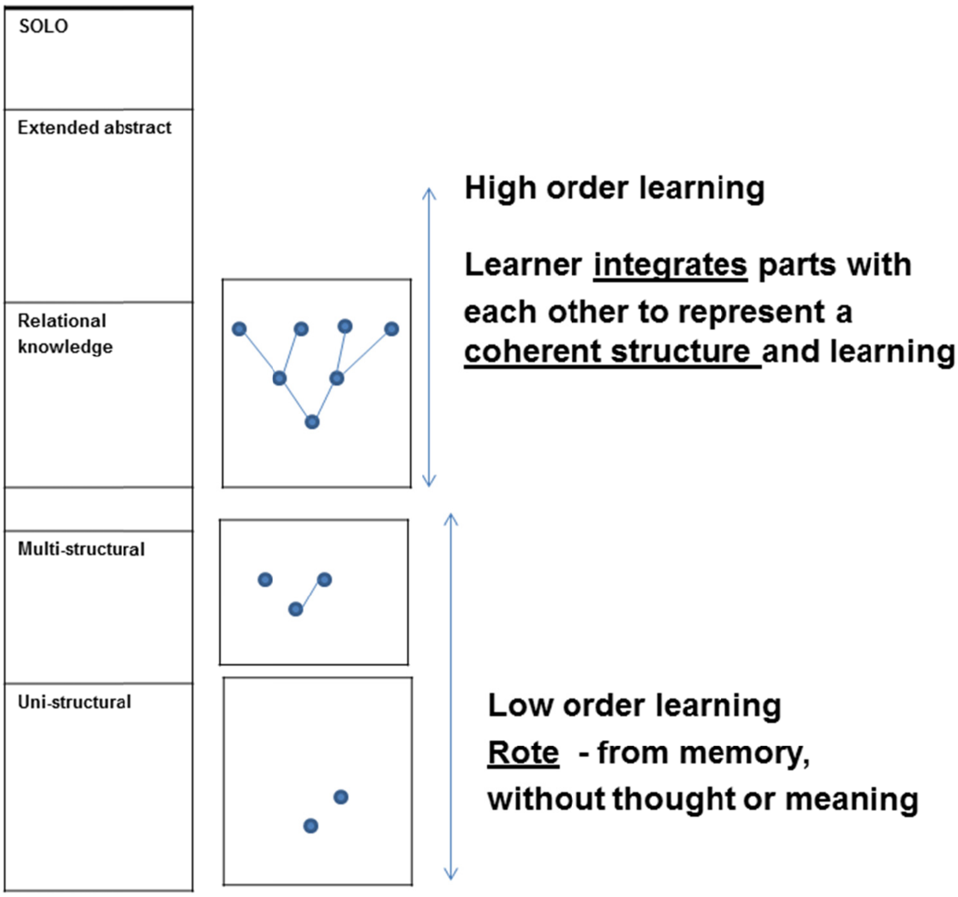

Figure 3. Structured high order relational knowledge

3.3 Linking Cognitive Science with SOLO Taxonomy

The SOLO taxonomy is a method of measuring the quality of learning ranging from low order rote learning to relational knowledge that is representative of a comprehensive understanding of the subject matter. In effect, with this level of understanding a student can correctly answer questions and more importantly explain ‘why’. Cognitive science defines the process of learning by the iterative process of retrieving a schema from long term memory in order to assimilate new learning material via short term memory. Short term memory is restricted in both its capacity and duration; long term memory is without these restrictions. The SOLO taxonomy and the cognitive map of learning may be combined in order to define the objectives of teaching and learning – relational high order learning resident in long term memory i.e. a schema. As Maj has demonstrated it is possible to quantitatively define the optimal learning path to facilitate the learning process. This optimal learning path can be used to define the sequence of learning or scaffolding in which the material goes from simple to complex in easy, small steps. When material is structured new material is contextualized and hence reinforces existing knowledge (Figure 4). Using this methodology State Model Diagrams were created as a pedagogical tool (S.P. Maj & Veal, 2007). An evaluation of teaching and learning based on this method clearly demonstrated quantifiable and significant improvements (S.P Maj & Kohli, 2004).

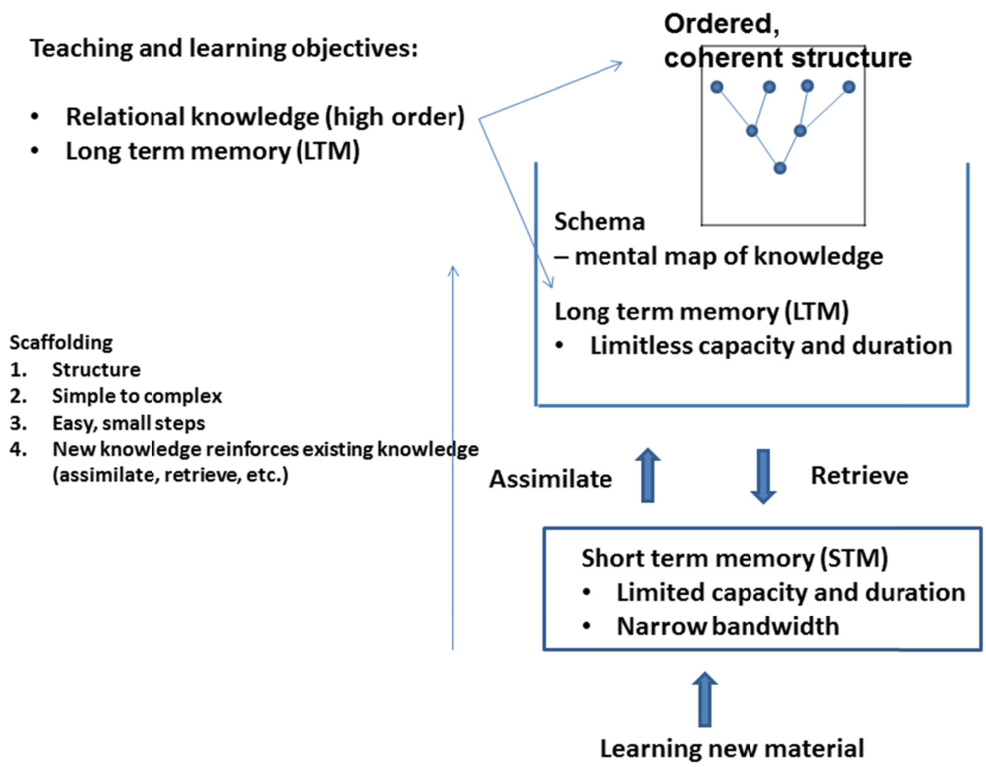

Figure 4. Linking SOLO taxonomy with cognitive science

4. Discussion

There are various learning theories each with their associated strengths and weaknesses. The strength of the cognitive model is that it is reflective of the two types of memory; their interaction and how knowledge is resident in long term memory as schemata. The quality of learning may be evaluated using the SOLO taxonomy which defines high order learning to be based on relational knowledge. Using the PAUP algorithm it is possible to define the optimal learning sequence and hence the easiest learning path. This paper has shown that the SOLO taxonomy and the PAUP algorithm can define the learning path represent how material may be scaffolded and hence transition from the simple to the complex in easy, small steps with new knowledge reinforcing existing knowledge. However further work is needed to determine if this method is applicable to other subject matters such as science, engineering etc.

References

Biggs, J., & Collis, K. (1989). Towards a Model of School-based Curriculum Development and Assessment Using the SOLO Taxonomy. *Australian Journal of Education, 33*(2), 151-163.

Bloom, B. S., Engelhart, M. D., Furst, E. J., Hill, W. H., & Krathwohl, D. R. (1956). *Taxonomy of Educational Objectives - The Classification of Educational Goals*. New York: David McKay Company, Inc.

Collis, K. F., & Davey, H. A. (1986). A technique for evaluating skills in high school science. *Journal of Research in Science Eduations, 23*, 651-663.

Dick, W. C. L. (1990). *The Systematic Design of Instruction* (3rd ed.). New York: Harper Collins.

Diekhoff, G. M. (1983). Relationship judgements in the evaluation of structural understanding. *Journal of Educational Psychology, 75*, 227-233.

Fisher, K. M. (1990). Semantic Networking: The new kid on the block. *Journal of Research in Science Teaching, 27*(11), 1001-1018.

Frase, L. T. (1969). The influence of conceptual clustering upon level of organisation. *Journal of Educational Psychology, 60*, 394-401.

Hanf, M. B. (1971). Paragraph organisation of written materials. The influence of conceptual clustering upon

Hattie, J., & Purdie, N. (1998). *The SOLO model: Addressing fundamental measurement issues*. Melbourne, Australia: Australian Council of Educational Research.

Jonassen, D., Beissner, K., & Yacci, M. (1993). *Structural Knowledge: Techniques for Representing, Conveying and Acquiring Structural Knowledge*. Hillsdale, New Jersey: Lawrence Erlbaum Associates.

Keppens, J., Hay, D. (2008). Concept map assessment for teaching computer science programming. *Computer Science Education, 18*(1), 31-42.

Krathwohl, D. R. (2002). A revision of Bloom's Taxonomy: an overview. *Theory into Practice, 41*, 4.

Larkin, J. H., & Simon, H. A. (1987). Why a diagram is (sometimes) worth ten thoasand words. *Cognitive Science, 11*, 65-99.

level of organisation. *Journal of Educational Psychology, 60*, 394-401.

Maj, S. P., & Kohli, G. (2004). A New State Models for Internetworks Technology. *Journal of Issues in Informing Science and Information Technology, 1*, 385-392.

Maj, S. P., & Veal, D. (2007). State Model Diagrams as a Pedagogical Tool - An International Evaluation. *IEEE Transactions on Education, 50*(3), 204-207.

Maj, S. P., & Veal, D. (2010). Parsimony Analysis - a novel method for structured knowledge representation for teaching computer science. *Modern Applied Science, 4*(11), 3-12.

McMillan, J. H. (2001). *Classroom Assessment: Principles and practice for effective instruction* (2nd ed.). Boston, MA: Allyn & Bacon.

Meyer, B. J. F. (1985). Signalling the structure of text. In D. H. Jonassen (Ed.), *Technology of Text* (Vol. 2). Englewood Cliffs: NJ: Educational Technology Publications.

Minsky, M. (1975). A framework for representing knowledge. In P. H. Winston (Ed.), *The psychology of computer vision*. New York: McGraw-Hill.

Nagy, P. (1984). Cognitive structure and the spatial metaphor. In N. P. (Ed.), *The representation of cognitive structure*. Toronto, Canada: Ontario Institute for Studies in Education.

Piaget, J. (1952). *The Origins of Intelligence in Children*. New York: International Universities Press.

Reigeluth, C. M. (1979). In search of a better way of organising instruction: The elaboration theory. *Journal of Instructional Development, 2*, 8-15.

Rumelhard, D. E. (1980). Schemata: The building blocks of cognition. In R. J. Spiro, Bruce, B. C., Brewer, W. F. (Ed.), *Theoretical issues in reading comprehension: Perspectives from cognitive psychology, linguistics, artificial intelligence, and education*. Hillsdale: NJ: Lawrence Erlbaum.

Skinner, B. F. (1948). *Walden II*. New York: Macmillan.

Team, A. T. F. T. A. L. (2004). *Cogntive Processes in asTTle: The SOLO Taxonomy*. Retrieved from

Vygotsky, L. S. (1978). *Mind in society: the development of higher psychology processes.* Cambridge, MA:: Harvard University Press.

Copyrights