eLmaps: An Educational Software Application Based on Principles of Cognitive Linguistics and Cognitive Science

MICHAEL TANG, TOAN TRAN, HYO-JEONG KIM, ANDREW HUND AND KAREN KNAUS
Abstract: This paper describes a new educational software application, eLmaps (efficient Learning maps). The application is part of a cognitive development educational system currently being developed by researchers at the University of Colorado Denver to increase the reading and thinking skills of high school and undergraduate level STEM (science, technology, engineering and mathematics) students. The educational software consists of: 1) a set of educational materials that emphasize the process of learning through logical and coherent structures that mirror basic thinking processes; 2) a learning method with multi-media materials centered on visual learning maps and critical-thinking principles; and 3) the integration of a strong reading and writing component to reinforce the development of thinking skills. The eLmaps application involves teaching high school and undergraduate college students how to use a set of visual learning maps to construct knowledge as they read and learn from complex STEM texts. The paper further suggests that student use of the eLmaps application may prove to be an extremely powerful computer-aided educational intervention because of key cognitive linguistic and cognitive science principles inherent in design.

Keywords: Educational Software, eLearning, Cognitive Science, Linguistics, Epistemology

INTRODUCTION AND BACKGROUND

Efficient Learning maps (eLmaps) is a software application written in HTML5, JavaScript and Visual Basic, designed to help students learn how to use a set of visual learning maps known as the “seven sisters” to logically construct knowledge as they reduce the complexity of information presented in STEM (science, technology, engineering, and mathematics) educational texts. The “seven sisters” visual learning maps consist of a set of seven geometric-like representations of basic set theory, which is a theory of categorization from which contemporary mathematical logic operations and processes are expressed. The “seven sisters” are examples of visual learning maps but they are different from other kinds of maps used for learning (e.g., “concept maps”, “mind maps”, “cognitive maps”) because they use a limited set of symbolic figures based on set theory and first-order logic from semantics and can be correlated back to a limited set of logical thought operations.

Subsequently, the researchers developed the “seven sisters” to help students develop cognitive skills for effectively reading and learning from complex STEM educational texts. These maps are integrated into their lesson plans as useful aids to help students study and organize complex textual information, solve problems and improve their reading and writing skills. The use of
linguistic/semantic visual maps to teach cognitive skills across the curriculum is a student-centered teaching and learning method that has been found to significantly improve student learning (Auwera, 2008; Carifio and Perla, 2009; Costa and Kallick, 2000; Hoening, Sim, Bochev, Herrnberger, and Kiefer, 2008; Hyerle, 1996; Hyerle, Alper, and Curtis, 2004; Hyerle, 2006; Hyerle, 2009; Ma, Kanzaki, Zhang, Murata, and Isahara, 2004). Recent literature suggests that the reason educational mapping materials are successful at promoting learning is that they may represent structures that are actually isomorphic with neurological cognitive patterns (Carifio and Perla, 2009; Costa and Kallick, 2008). The original use of such maps had been proven successful approximately 50 years ago with undergraduate college students by Upton (1961).

In developing the “seven sisters”, it should be emphasized that the maps are a kind of mathematical symbols used for exegesis that is the interpretation of text and not of the natural world which is the main business of natural science. Figure one is a well-known image “Magritte’s pipe” famous in the field of semiology, a closely related field to linguistics that involves the study of signs and sign processes. “Magritte’s pipe” is used to illustrate the distinction between analysis of objects and events in the world and the analysis of text or symbols. The French words below the picture say, “Leci n’est pas une pipe”, which is translated in English to say, “This is not a pipe,” which means that the painting is not a pipe or as the Buddhists would say, “Do not confuse the finger pointing to the moon with the moon.”

![Magritte's Pipe](http://www.friendsofart.net/static/images/art3/rene-magritte-this-is-not-a-pipe.jpg)

In addition, the formal logic aspect of the use of visual learning maps should not be confused with the mathematical aspects of transformational grammar. The “seven sisters” visual learning maps described in this paper that help students construct conceptual models of understanding are not concerned with syntax or grammar but with meaning; furthermore, the logic in the maps is derived from semantics rather than formal linguistics made popular by Chomsky (1966).
Cognitive Linguistic and Cognitive Science Influences

Several influences on the development of the “seven sisters” visual learning maps from computer science, linguistics and semantics include: (1) Ogden (1946, 1967, 1968); (2) Richards (1968); (3) Upton (1961, 1963); (4) Berners-Lee (2000, 2005, 2006); (5) Schank (1969, 1973, 1976); and (6) Lakoff (1970, 1978). Ogden was one of the co-authors of *Tractatus Logico-Philosophicus* (1922), one of the most influential works on the history of the philosophy of logic. Richard co-authored the classical semantics book, *The Meaning of Meaning* (Ogden and Richards, 1946), and wrote the preface for *Upton’s, Design for Thinking* (1961), which detailed the basic theory and maps that served as a model for the construction of the “seven sisters” visual learning maps described in this paper.

There also exists a theoretical basis in cognitive science to support the efficacy of the “seven sisters” visual learning maps and the eLmaps application. The integration of three very important theoretical frameworks for learning can be used to understand why the “seven sisters” visual learning maps are effective: (1) cognitive load theory; (2) constructivism; and (3) cognitive theory of multimedia learning.

One of the major pillars of cognitive load theory (Sweller, 1988) is that effective instructional materials avoid overloading students’ working memory (Baddeley, 1992; Miller, 1956), which then allow learners’ to direct their attention to relevant learning processes (Kester, Kirschner, and van Merriënboer, 2005). On the other hand, constructivist learning theory provides a basis for understanding how people incorporate new knowledge into existing knowledge and then make sense of that knowledge (Ferguson, 2007; Nussbaum, 1989; Tobin, 1990; Von Glasersfeld, 1992). According to Fosnot and Perry (2005) the goal of constructivism is “cognitive development and deep understanding” (Ferguson, 2007; Fosnot and Perry, 2005). Piaget, the famous Swiss developmental psychologist, has been credited as being the originator of constructivism (Von Glasersfeld, 2005). Specifically, Piaget set forth key ideas that learning occurs in stages, and knowledge is organized as cognitive structures (Brooks and Brooks, 1993). It has also been cited that constructivism should be used as a theoretical framework for education research when the goal of the study is to describe cognitive structures of the concepts held by the learner (Cobern, 1983). Furthermore, cognitive load theory and the constructivist theory of learning also provide relevant theoretical frameworks to support the efficacy of the “seven sisters” visual learning maps as an educational intervention.

The cognitive theory of multimedia learning (Mayer, 1997) involves several ideas that support the use of multimedia materials for learning (Mayer, 2001). For example, the “multiple representation principle” involves the idea that it is better to present an explanation in words and pictures (a.k.a. “an integrated format”) rather than solely in words (Mayer and Moreno, 1998). The “spatial contiguity principle” involves the idea that students learn better when corresponding words and pictures are presented near rather than far from each other on the page (Mayer, 1989; Mayer, Steinhoff, Bower, and Mars, 1995), and the “individual differences principle” involves the idea that educational design effects are stronger for low-knowledge learners than for high knowledge learners, and for high-spatial learners rather than for low-spatial learners (Mayer and Moreno, 1998; Mayer, 2001). For example, previous studies demonstrated that students who lacked prior knowledge showed stronger multimedia effects than students who had higher levels of prior knowledge (Mayer and Gallini, 1990; Mayer et al., 1995; Mayer and Moreno, 1989). Furthermore, the cognitive theory of multimedia learning further supports the design of the eLmaps application which provides the medium (i.e., the computer) to help teach students and their teachers how to use the “seven sisters” visual learning maps.

Guided by the cognitive linguistic and cognitive science frameworks discussed in this paper, the researchers are currently implementing and assessing the efficacy of the “seven sisters” visual learning maps and the eLmaps application to validate the hypothesis that they can help
facilitate the construction and organization of knowledge networks among students and assist them in the mastery of undergraduate material on a higher cognitive level.

**Seven Sisters Visual Learning Maps and the Efficient Learning Maps Application**

Efficient Learning maps (eLmaps) is a software application written in HTML5 and JavaScript to teach students how to use visual learning maps that help them associate and organize information logically for systems thinking and analysis. The efficient learning maps application is based on the use of seven basic visual learning maps known as the “seven sisters”.

Each of the “seven sisters” visual learning maps asks and answers a specific set theory or first-order logic question concerning relationships which in natural language are represented by logical thought expressions such as, “is a kind of”, “is a part of”, “is a quality of,” and the like. More precisely, the questions asked are as follows:

![Matrix of Logical Thought Expressions Found in the “Seven Sisters” Visual Learning Maps](image)

It should be emphasized that the “seven sisters” visual learning maps serve as a set of visual tools that have been limited to the analysis of academic discourse and not of nature per se as is the province of science proper; although it is possible they could be used in the latter manner as well. Hence, we had students use the “seven sisters” visual learning maps to simplify complex STEM textual material about science and not processes in the natural world, such as what a student would find in a chemistry laboratory.

An example of complex STEM textual material that a student might encounter during an undergraduate college course might be the following:

In the 19\textsuperscript{th} century, pure aluminum was considered a rare and precious metal. As a result, very wealthy and powerful persons had artifacts made out of aluminum. For example, in Europe, Napoleon III had a dinnerware set made out of aluminum and may have used this dinnerware set to impress his guests. In the U.S., the capstone on the Washington monument bearing the inscription, “the forefather of our country” was also made out of aluminum. Through the unification of basic and applied research in both chemistry and engineering, the transformation of aluminum as a rare and expensive material in the 19\textsuperscript{th} century to a common and inexpensive metal in the 21\textsuperscript{st} century was made possible.

The process by which pure aluminum is obtained from raw materials is known as aluminum refinement. Aluminum can be refined from a substance known as “bauxite” which is found in mineral rocks. The refinement of aluminum from bauxite is a multiple-step process which involves separating aluminum particles from other chemical components in the rock. The first major step of aluminum refinement involves washing bauxite with caustic soda.
This process helps separate the aluminum oxide from the solid rock. The second major step of aluminum refinement involves inserting carbon rods into the remaining aluminum oxide mixture. Then, an electric current is applied to the carbon rods and a chemical reaction takes place where and oxygen atoms from aluminum oxides combine with carbon atoms from the carbon rod to produce carbon dioxide gas. The carbon dioxide gas (CO$_2$ (g)) is considered a by-product in the chemical reaction. Finally, aluminum particles can be separated from the remaining chemical mixture based on density differences between aluminum, which has a lower density than other chemical components in the mixture.

Over the past two centuries engineers have been able to design and improve upon large-scale machinery that has helped transform the process of aluminum refinement into a practical and cost efficient process. Moreover, it was through almost three centuries of interdisciplinary research between the fields of chemistry and engineering that aluminum was also transformed from a rare and expensive material to a common and inexpensive material. One might even say that this interdisciplinary research effort between chemistry and engineering brought us just one step closer to each other. Furthermore, many people on this planet, regardless of their culture, economic status, position of power or influence, can easily obtain aluminum products such as a can of soda pop.

Analysis of this reading passage using the logical thought expressions in figure 2 leads to the following ideas:

1. Rare, precious and expensive were *properties of aluminum in the context of the 19th century*.
2. Wealthy and powerful were *properties of persons who owned aluminum products in the context of the 19th century*.
3. Washing bauxite with caustic soda is a *stage of the process of aluminum refinement*.
4. Applying a carbon rod with an electric current to aluminum oxide mixture is a *stage of the process of aluminum refinement*.
5. Separation of aluminum particles from other components through differences in density is a *stage of the process of aluminum refinement*.
6. Basic and applied are *types of scientific research*.
7. Chemistry and engineering research are *parts of interdisciplinary research*.
8. Common and inexpensive are *properties of aluminum in the context of the 21st century*.
9. Culture, economic status, power and influence are *properties of a person that are not important for obtaining aluminum products in the context of the 21st century*.

When these logical thought processes are diagrammed, reconfigured, or translated into their corresponding visual learning maps, they can be used to create a non-linear, systems analysis of the reading material that can later be used for study or a writing project.

For example, the above analysis can be diagrammed as follows according to our individual maps, the first of which is the tree map which triggers the user to do a classification analysis or genus species analysis:
Analysis

Research

basic
applied

Structural analysis = parts analysis:

\{
\}

Analysis

Interdisciplinary research

\{ chemistry
engineering\}
Properties analysis = qualities analysis:

Analysis

Operational Analysis = process analysis:

Analysis
In the above map, a person in the 19th century is compared to a person in the 21st century and aluminum products are compared to gold products; therefore, a similitude analysis is made between a person in the 19th century and aluminum products and a person in the 21st century and gold products. The similitude analysis is a more complex and creative analogy.
Matrix = context analysis of another map:

Analysis 1: Frame = In the 19th century

Analysis 2: Frame = In the 21st century
From an epistemological and pedagogical perspective, one that is concerned with the nature and scope of knowledge, students applied the “seven sisters” visual learning maps to comprehend reading material. Analogous to this idea is what the French called, “exposition du texte,” exegesis or the interpretation of textual material. In this study, we concluded that although grammar and syntax may not correspond to the natural laws of classical science (Cassirer, Manheim, and Hendel, 1985; McLuhan and McLuhan, 1988), they do correspond to linguistic laws and formal logic which in turn may correspond to neurological patterns associated with thinking. Given this context, it is our theory that students will improve their cognitive skills by using the “seven sisters” visual learning maps to analyze STEM textual material with the eLmaps as a computer-aided tool to construct knowledge in mapping, graphic or diagrammatic forms.

In our studies with students using the “seven sisters” visual learning maps, we found that contrary to popular opinion, logic can be fun if it is not taught as linear abstract statements but visual manifestations of logical patterns in the form of visual learning maps to analyze thoughts and concepts found in textbooks. The “seven sisters” visual learning maps give the students a practical tool to master academic material, mainly university texts, for a practical and desired end that is to organize information in a non-linear but highly structured way for better understanding and improved memory retention. In using the maps to reduce complex ideas to simpler structures, according to the rules of the computer program to translate or re-configure linear text to graphic structures, the students are doing logical analysis rather than merely reading about the process. In connecting the maps to each other via the hyperlink, they are engaging in creative thinking by linking simpler ideas to construct more complex and often original concepts.
Discussion and Conclusion

To analyze and explain what the “seven sisters” visual learning maps are and how they work, we have taken another visual learning map, one developed by McLuhan (1988), which he called “The Tetrad” and placed it within the framework of a complex analog map (figure 5). When used to analyze an artifact or an idea, McLuhan’s Tetrad:

- retrieves something from the ground;
- obsolesces something else and sends it back to the ground;
- enhances aspects of that artifact, idea, or media to the foreground;
- and flips to (or reverses) the qualities of the artifact into something else possibly it’s complete opposite.

![Figure 3: Ideas of McLuhan's Tetrad Expressed Within a Complex Analog Map (One of the “Seven Sisters” Visual Learning Maps)](image)

Given this analysis, each of the “seven sisters” visual learning maps (including the analog map):

1. **Enhances**
   a. Visual-spatial learning
   b. Associative thinking via the hyperlink
   c. Logical thinking
   d. Systems thinking

2. **Obsolesces**
   a. Phonological loop
   b. Sequential thinking

3. **Retrieves**
   a. Geometry
   b. Grammar
Moreover, the medium, the eLmaps application, fits well with the message, the visual learning maps, in that both enhance structural patterns, logical thinking and associate thinking important to the development of higher order thinking processes. As a computer program, eLmaps enhances associative thinking via the hyperlink, obsolesces the sequential and algebraic algorithms, and retrieves geometry, grammar, logic, and meaning. Moreover, according to a forthcoming book by Hyerle, the maps themselves are extremely powerful because:

1. there are a limited number of fundamental, dynamic cognitive processes, or what have been called “mental operations” and limitless iterations of these processes;
2. these cognitive processes, grounded in neural structures, generate relationships between bits of information, forming naturally occurring, often unique patterns of information; and
3. nonlinear patterns are significantly under-represented by the normal use of linear strings of words and numbers within and across language communities.

Cognitive processes visually drawn from primitive visual patterns such as the “seven sisters” visual learning maps are more congruent with underlying patterns of thinking than are ideas and concepts manifested in linear written or spoken text. One way to visualize the reason these maps are so effective in learning is to imagine each map as a chess piece with its own moves or functions. Although the number of pieces or maps is limited, the maps or pieces can be combined in limitless ways to form or analyze thoughts manifested as verbal text. These symbols of thought, like chess pieces, can express meaning ranging from the very basic and elementary to the extremely complex.

**Acknowledgements**

The authors would like to thank the many students and teachers who served as the inspiration for this project and The University of Colorado Denver for start-up research funds and support on this project.
REFERENCES


ABOUT THE AUTHORS

Michael Tang: Michael Tang is the Founder and Senior Partner of VERI Books, LLD with the mission of preserving and redefining literacy in a multi-media culture and society dominated by the information technologies and the World Wide Web. He is also adjunct associate professor and senior lecturer in the College of Engineering and Applied Science, where he teaches courses in Science, Technology and Society (STS) and conducts research on the impact of new technologies on culture and society. He attended Whittier College in California and graduated with a Ph.D. in the History of Science from the University of Wisconsin at Madison.

Toan Tran: Toan Tran is an associate software engineer at Raytheon Corporation in Marlborough, Massachusetts. He, Michael Tang and Matthew L. Tang are the lead programmers behind the eTutor software application. Tran will return to Denver Colorado in the Summer of 2013 to begin graduate studies in computer science at Colorado State University in Fort Collins, Colorado. Toan graduated at the top of his class in computer science at the University of Colorado Denver and place 2nd nationally in university computer science entrance exams in Vietnam before transferring to the University of Colorado.
Hyo-Jeong Kim: Kim Hyo-Jeong is an adjunct faculty at University of Denver and University of Colorado Denver. She finished her Ph.D. degree in Computer Science and Information Systems from University of Colorado Denver. Her scholarly interests range widely from the impact of information technology on business to marketing, government, and education. She has been involved in many IT research projects as a programmer developing the web based information system for improving task performance.

Andrew Hund: Andrew Hund is an assistant professor of sociology at the United Arab Emirates University in Al Ain. His research interests include development of educational materials, women’s studies and health disparities of cultural groups. Andrew earned a doctorate in the areas of Sociology and Gerontology from Case Western Reserve University in Ohio.

Karen Knaus: Karen Knaus is an assistant professor of chemistry at the University of Colorado Denver. Her research interests include the development of educational materials that improve the logical, connective and creative thinking abilities of college students. Other interests include shared leadership, collaboration, co-mentoring and family life. Previously, Karen served as a research fellow at the American Chemical Society (ACS) Exams Institute. Karen’s doctoral work specialized in computational/theoretical chemistry and she received her doctorate in the area of Clinical/BioAnalytical chemistry from Cleveland State University in Ohio.
The International Journal of Technology, Knowledge and Society explores innovative theories and practices relating technology to society. The journal is cross-disciplinary in its scope, offering a meeting point for technologists with a concern for the social and social scientists with a concern for the technological. The focus is primarily, but not exclusively, on information and communications technologies.

Equally interested in the mechanics of social technologies and the social impact of technologies, the journal is guided by the ideals of an open society, where technology is used to address human needs and serve community interests. These concerns are grounded in the values of creativity, innovation, access, equity, and personal and community autonomy. In this space, commercial and community interests at times complement each other; at other times they appear to be at odds. The journal examines the nature of new technologies, their connection with communities, their use as tools for learning, and their place in a “knowledge society”.

The perspectives presented in the journal range from big picture analyses which address global and universal concerns, to detailed case studies which speak of localized social applications of technology. The papers traverse a broad terrain, sometimes technically and other times socially oriented, sometimes theoretical and other times practical in their perspective, and sometimes reflecting dispassionate analysis whilst at other times suggesting interested strategies for action.

The journal covers the fields of informatics, computer science, history and philosophy of science, sociology of knowledge, sociology of technology, education, management and the humanities. Its contributors include research students, technology developers and trainers, and industry consultants.

The International Journal of Technology, Knowledge and Society is a peer-reviewed scholarly journal.