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ABSTRACT

This paper examines how visual information strategies mey be used to facilitate the development of mental models. Topics covered include: definition of mental models; mental models and visual information; mental modeling concepts; power of modeling, including examples related to physical science, mathematics, writing, and depth of processing; information transformation; and a discussion of Visionnaire, a systems modeling software program. (Contains 16 references.) (JLB)

Visual Information Strategies in Mental Model Development

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We are not born *tabula rasa*. It is a perception that an individual's cognitive structure is a result of the modeling methodologies acquired through experience. Mentally constructing models to serve as representations of objects and events is fundamental to cognitive functioning. Donald (1991) suggests that modeling advances cognitive functions to higher levels in an individual's search for the power to resolve ambiguities and to support a certain level of culture. Thus, an individual's inherent drive to mentally engineer increasingly powerful models of the world, built upon information, is the engine powering cognitive development.

> It is an individual's nature to mentally model objects and events.

Mental Models

A mental model is a domain-specific representation of an object or event used to explain or predict. The American Heritage Dictionary (1979) defines mental as: "Done or performed by the mind; existing in the mind." Further, the American Heritage Dictionary (1992) defines a model as: "A schematic description of a system, theory, or phenomenon that accounts for its known or inferred properties and may be used for future study of its characteristics." Thus, a mental model is created and exists in the mind as a description of a system, theory, or phenomenon.

Scientifically, the term mental model seems to elude such a concise definition. Definitions range from Minsky's (1985, 1986) suggestion that a mental model is anything that helps an individual answer questions about something, to Norman's (1983) definition of "an often technically inaccurate naturally evolving representation of a target system that is. . .incomplete. . .unstable. . .lacks firm boundaries. . .unscientific. . .and are parsimonious."

Synthesizing available literature, mental model is defined as:

- personal mental representations of objects or events;
- domain-specific; and
- used by individuals to explain or predict.

These three characteristics are the keys to crafting a visual environment with software tools to assist in mental model development. A mental model is a representation, thus it has structure. A mental model is domain-specific, therefore, a domain may be identified and modeled. A mental model is used to explain or predict, thus, causal relationships are externally modeled then extracted from the model by the viewer to serve this function. Employing visual information to model a system's structure and inherent causal relationships are thus crucial in assisting the viewer with mental model development.

> Mental models are domain-specific representations used to explain or predict.

Mental Models and Visual Information

Visual information may be presented via visual media to influence the development of a viewer's mental model. Visual information consists of the pictures, graphic symbols, or other imagery used in visual communication. Visual communication is the use of visual information to convey meaning. Mental models are built from personal interpretation of information. Information is stored in mental structures called knowledge bases and is acquired through the senses with the visual system providing one of the densest paths of information. Saunders' (1994) suggestion that visuals appeal to the intellect and communicate, as well as Ballstaedt, Mandl, and Molitor's (1989) suggestion that visual media may be used to facilitate the construction of a mental model, leads one to the conclusion that visual information has the potential to impact mental model construction via communication of a system's structure and causal relationships.

> Visual Information Facilitates Mental Model Development

Mental Modeling Concepts

Visual information presented to assist in the development of mental models must provide a visual model that is analogous to an actual system and allows the inference of causal relationships. Seel and Strittmatter (1989) suggest that the minimum precondition for mental model construction is analogous structures between the original system and the model. The degree of correspondence between the model and original is further determined by the degree of similarity between the attributes and inferred causal relationships existing between the attributes for each. Seel and Strittmatter seem to further postulate:

- Mental models do not develop automatically. They develop through conscious information processing.
- Mental models are built from personal interpretations of existing knowledge bases that represent a specific domain of the external world. Mental models thus result from an individual's interaction with personal knowledge bases.
- Since mental models are developed from knowledge bases, images only ignite the development of mental models and assist in making the models concrete.
- Illustration serves two functions: mapping and heuristic. The mapping function is the delivery of facts by the media. The heuristic function initiates thinking.

Analogy-making, important in Seel and Strittmatter's (1989) concept of mental model development, was suggested by Mitchell (1993) as the mechanism for distilling the essence of a situation and transportation to a different situation and adapted via conceptual slippages. Conceptual slippage occurs when a concept embedded in an existing mental model is put under pressure from

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(1986) suggests that the visual component or system of information storage is initially used in problem-solving to rotate and examine the problem space. The verbal system is then incorporated into the examination to probe and analyze the problem space further. Mental models facilitate mental investigation because they may be manipulated during exploration. Usage of mental models in this capacity is present in the areas of physical sciences, mathematics, and writing. Mental models also facilitate the depth of information processing, therefore, resulting in greater understanding, retention, and transference to novel situations.

Physical Science

In the field of physical science, Einstein achieved his greatest insights via engagement with mentally visualized systems of light waves and idealized physical bodies (Shepard, 1978). James Clark Maxwell arrived at Maxwell's equations, not by logical reasoning, but by a series of increasingly abstract hydrodynamic and mechanical models of the medium (Shepard, 1978).

Mathematics

Mental model development specific to mathematics may benefit from engagement via visual information with mathematical theories, principles, and concepts. Piaget's theory of cognitive development suggests that cognition progresses from concrete representation to abstract representation as one ages. Perl (1993) relates that tools called "manipulatives" are used to assist this progression. Manipulatives are concrete, physical objects that can be manipulated and visually inspected. In mathematics, manipulatives are used to *model* abstract concepts. Experimentation with manipulatives assists the movement from concrete to abstract representations; from fragmented facts and concepts to mental models.

Perl (1993) provides the example of the use of brightly colored geometric shapes called attribute blocks as manipulatives. The attribute blocks come in four shapes, each in three colors, and of two different sizes. School children build a "train" from the blocks, with adjacent blocks varying by only one characteristic at a time. The attribute blocks provide highly visual, concrete stimuli to foster mental model development of abstract theories.

Writing

Carley and Palmquist (1992) suggest representing mental models as visual maps extracted from written and spoken prose. Underlying concepts and structures may then be analyzed. An implication is that such visualization could assist in the *development* of mental models necessary for one to write. The maps can be explored and manipulated, serving to create and refine mental models of prose structure and rules.

Depth of Processing

Mental models are multi-dimensional and possess informational depth. Visual three-dimensional modeling provides a visual environment that is information-rich and is multi-dimensional. Visual three-dimensional modeling, whether of objects or events, is built on data. Data for specific modeling applications may be required from a vast array of disciplines. Therefore, data collection requires active thinking regarding what data is needed, from where, and in what form. Such an environment provides for the social sharing of cognition (each discipline participant's mental model is affected by the other different discipline participants). Further, in the area of graphing, Schwartz (cited in Kinnaman, 1993) believes that one must be able to *enter* a graph and *see* the corresponding changes in symbolic form of the function itself. Visual information portrayed in this manner would allow the viewer to enter the system itself and navigate via their mental model that is continually being updated through feedback from hypothesis testing.

Mental models are powerful tools in an array of disciplines. The models may be built on visual information and serve to facilitate mental investigation.

> Mental models can be tools, built on information, that facilitate mental inquiry.

Information Transformation

Information, the building block of mental models, is accelerating in production. Time, as a personal commodity with which to attend and process this accelerating information base, is diminishing. Mental model strength is dependent on updated, comprehensive information that may be perused and perceived timely. Thus, the nature of information must change from primarily text-based to imagery-based.

The nature of information is changing. White (cited in Fredette, 1994) suggests "the change in information is a shift from print to imagery as the medium for information delivery, transformation, and exchange." White further asserts that imagery is our major information carrier.

This trend is exemplified in today's instructional media such as multimedia; of a world community requiring communications to be interpretable across cultures; and in mathematical concepts being envisioned pictorially. Alas, the bold escape from Edward Tufte's (1990) "flatland" created by textual information is underway. Imagery, or visualized information, is becoming the new nature of information. Increasing computational power may be harnessed to capture and deliver visual information to assist in the development of mental models.

> Imagery is becoming the new nature of information.

Visionnaire™-- A Tool

Visionnaire™ is a systems modeling software program developed by AT&T Bell Laboratories initially to assist in clarifying large, complex telecommunications switching systems. The Instructional Design, Development and Evaluation (IDD&E) department within the School of Education at Syracuse University is engaged in a collaborative effort with Bell Laboratories to investigate the applications of Visionnaire™ as an instructional systems and mental modeling tool.

Visionnaire™ runs on a Sun™ computer under OpenWindows™. Visionnaire™ uses a Video Studio Metaphor to support rapid prototyping and improve ease of use by non-programmers. The Video Studio Metaphor is based on the analogy of video store operations and film production. The graphical user interface is that of a VCR as shown in Figure 1. The application development interface incorporates visual programming techniques and revolves around the analogy of film production. The developer describes and records the "scripts" that specify the relationship and subsequent action between two or more objects called "actors". Scripts may execute sequentially or in parallel and at various levels of system information detail. A collection of scripts and actors comprise a scenario and are stored as a tape, similar to a VCR tape, for later use.

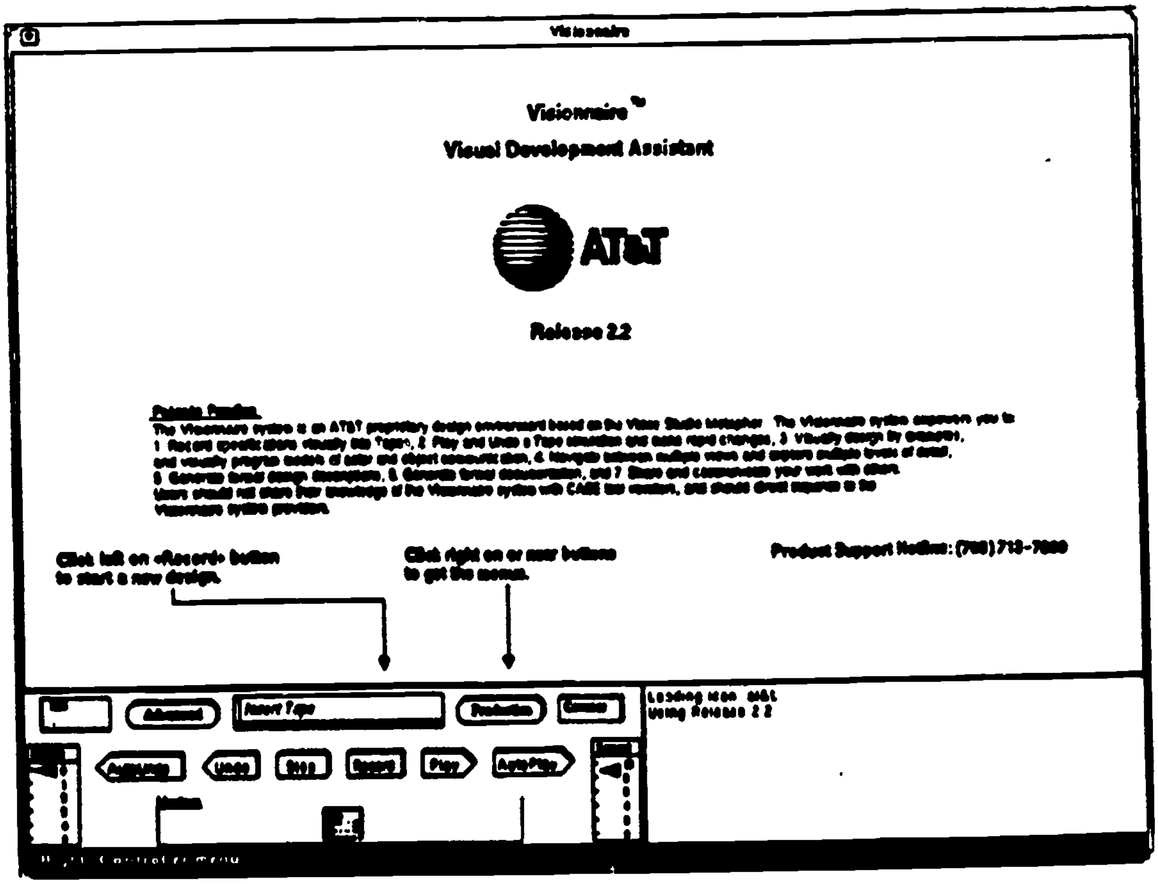


Figure 1
Visionnaire™ Video Studio Metaphor Interface

The core of Visionnaire™ is a knowledge-based simulation engine. Scenarios are represented through object-oriented programming techniques that construct rules of the IF...THEN format. Thus, scenarios are dynamic with pre-conditions and post-conditions of scripts considered and altered during execution, thus changing the state of the actors involved.

Visionnaire™ has been used with switching systems engineers as a vehicle for interactive, dynamic presentations of switching system specifications at design reviews. Visionnaire™, with its animated graphics, visual programming, and script-based scenarios has potential use in modeling abstract complex systems. It is this potential use that was investigated in the collaboration between IDD&E and AT&T Bell Laboratories.

Visionnaire (TM) is used to visually model dynamic systems.

The Canvas Under Visionnaire™

Building upon the aforementioned concepts, Visionnaire™ was used to create an animated visual environment on a Sun™ computer that would ignite the development of a mental model of the Instructional Systems Design (ISD) process. This was accomplished by representing the facts and structure of the process and the relationships that drive the process that constitute the essence of ISD. The animated visual environment serves to initiate thinking by displaying changing relationships amongst objects that changed the objects themselves. Simultaneously with Seel and Strittmatter's (1989) theory of mental model development. facts associated with the concepts of dimensionality, shape perception, and image perception were utilized.

Dimensionality

For years artists have used basic truths concerning depth perception to give their artwork a three-dimensional orientation. Kelsey (1993) reports that size, perspective, and shadowing provide one with clues as to the relationship between objects. We perceive larger objects as closer than smaller ones, distant objects as higher on the horizon than closer ones, and objects that appear shadowed by other objects as further away. An additional clue is provided through color. Bolder colored objects are perceived as closer then lighter colored objects.

Shape Perception

Marr (cited in Hendee, 1993), a psychologist who studied perception and its relation to cognition, suggested a three-stage process by which the perception of object shape occurs. First, there is the "primal sketch" of an object's features and intensity variations. Second, there is the identification of more subtle characteristics such as depth referenced to a coordinate frame centered in the viewer. Third, there is mental engineering on the part of the viewer of a three-dimensional model of the object. This process yields a mental model of the object suspended in cognitive "space".

Bottom-Up vs. Top-Down

Kelsey (1993) relates the two competing models for how an image is perceived: the bottom-up model and the top-down model. The bottom-up model suggests that an image is perceived by sequentially building up individual features into a recognizable whole. The top-down model suggests that an immediate "whole" impression, or "gestalt", is formed with the individual features filled in at later stages. Evidence supports both models. Because specific nerves only fire when presented with specific features, and that feature detectors exist in the visual system, support the bottom-up model. The top-down model is supported by our ability to quickly differentiate objects, such as faces we recognize versus those we don't in a crowd.

Weidenmann's (1989) work provided an additional consideration in the design of the Visionnaire™ visual environment. Weidenmann (1989) suggests that a viewer may falsely perceive visual information as non-informative initially and stop processing information. The creator of visual environments must make a conscious effort to protect against superficial attention on the part of the viewer. That is, a creator's desire is to have the viewer engage the visual environment rather then having the viewer complete an initial scan of the environment, consider the environment non-informative, and mentally disengage. The visual environment is arranged so the first scan by the viewer creates an expectation within the viewer that the environment is informative. Thus, information-processing of the visual information is not interrupted, or worse, terminated.

Visionnaire (TM) is used to paint a dynamic, visual environment.

Visionnaire™-- The Engine and Palette

The visual information environment painted by Visionnaire™ incorporates Seel and Strittmatter's (1989) theory of mental model construction, and the facts associated with dimensionality, shape perception, image perception, and superficial attention. Visionnaire™ paints the visual environment pictured in Figure 2.

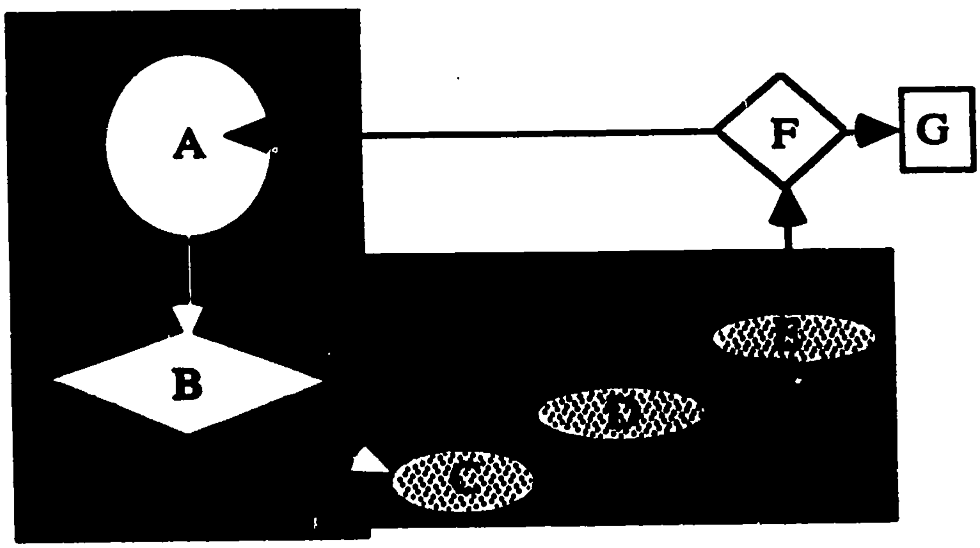
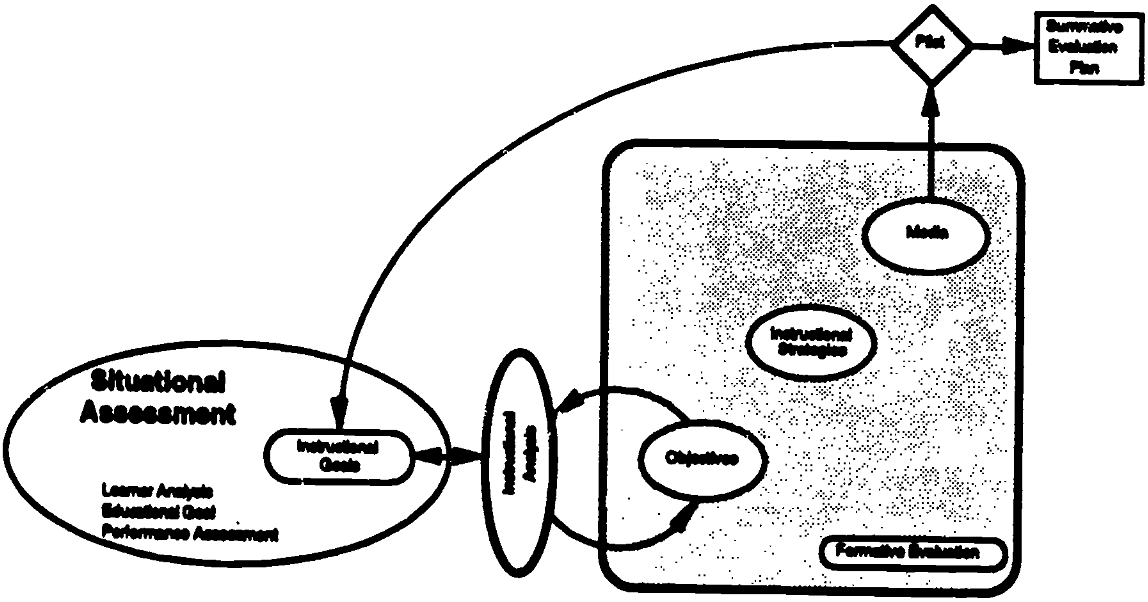


Figure 2

Key:
A- Situational Assessment
B - Instructional Analysis
C - Objectives
D - Instructional Strategies
E - Media Selection
F - Pilot
G - Summative Evaluation Plan

Initial viewer engagement with this environment is at an animated level. Upon viewer selection of "play", the ISD process is animated, with interaction occurring amongst the objects (A, B, C, D, E, F, G). The interactions change the color and size of the objects signifying the influence that actions have on the different stages (represented by the objects) of the ISD process. Thus the essence of the ISD process is demonstrated. The ISD process is systematic and systemic. That is, the ISD process is composed of interrelated parts that interact to achieve a goal. Yet a change in any one part changes at least one other part of the system. This initial engagement is designed to guard against superficial attention on the part of the viewer. Additionally, this approach complies with the top-down model of image perception. The ISD process is initially presented as a gestalt, with specific features filled in gradually throughout the cognitive engagement.

Utilizing Seel and Strittmatter's (1989) theory of mental model construction, the structure of this visual environment closely parallels the original ISD schematic represented in Figure 3.



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Instructional Design, Development and Evaluation

Figure 3
Fundamental Components of the Instructional Design Process

The structures are nearly identical thus providing a general analogy to be drawn between the original and the model. Completion of the analogy requires the causal relationships between objects to be demonstrated. This is accomplished through animated interactions amongst objects. Textual messages move from one object to the next. Upon receipt of a message, the object evaluates the message, and formulates an inquiry back to the sending object if the message is evaluated as incomplete. Upon receipt of a returned message, the sending object elaborates on the message and re-transmits the message to the recipient. Upon re-transmittal, the sending object disappears from the visual display. This signifies the true-to-life fact that time is a constraint on the overall process. There is not unlimited time to clarify and refine questions raised through evaluation at various stages of the ISD process. At this point, the recipient re-evaluates the message, performs the activity directed by the message, and generates a new message to the next object in the system. This activity parallels the bi-directional relationships that exist between various components of the actual ISD process itself. Dynamic activity of this nature is demonstrated in Figure 4.

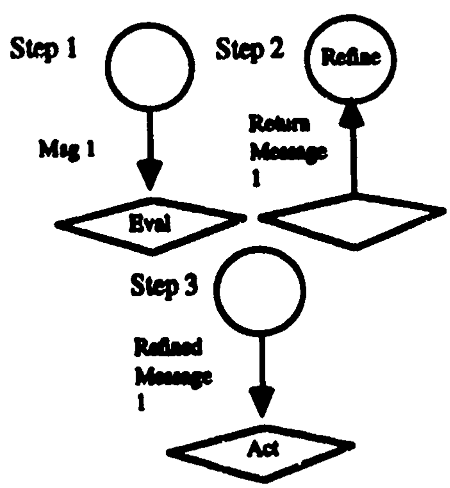

Figure 4

In summary thus far, the visual environment portrays the structure, composed of objects representing the "attributes", "facts" or "components" of the ISD process, and displays the causal relationships amongst the objects. One last component required portrayal to accurately depict the essence of the ISD process. This component is the sense of movement as a function of time. This component is captured by the backgrounds of the various objects as shown in Figure 5.

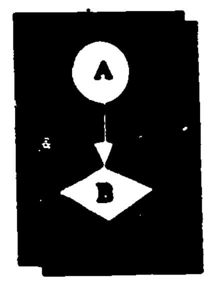

Figure 5

Applying the concept that objects with darker, bolder colors are perceived closer then lighter colored objects, black is chosen as the background for object A and B. Objects A and B represent the components of the general "input" phase of the ISD process. These components comprise events that occur early in the ISD. Extending this scheme, the components representing the "process" (formative evaluation) phase of the ISD process are highlighted against a gray background as depicted in Figure 6. Typically, these components occur midway through ISD.

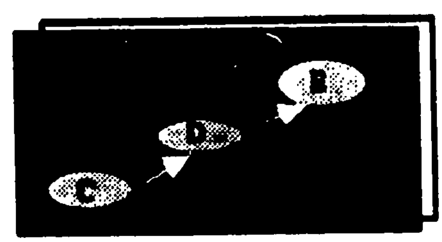

Figure 6

Completing this scheme, the components that represent the "output" phase of ISD are highlighted against a white background as demonstrated in Figure 7.

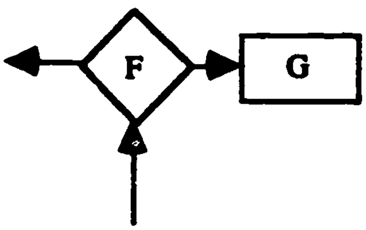

Figure 7

A final consideration concerns the objects themselves. The perception of depth and movement in time as the viewer progresses through the ISD process is augmented by a gradual decrease in object size and color intensity. Object A is the largest object; object G the smallest. Object A is a bold color. Object G is white. Objects B through F decrease gradually in color intensity.

Conclusion

Visual information strategies may be used to facilitate the development of mental models. To be successful, visual information strategies must allow portrayal of the structure of the system to be modeled, allow the inference of causal relationships, and depict the essence of the modeled system. Software tools exist to assist in the generation and presentation of visual information in the execution of those strategies.

Mental models, and the world they represent, are dynamic entities that interrelate in nonlinear, seemingly chaotic ways. Advanced strategies must be developed in the design and use of visual information to capture and portray the essence of dynamic entities. Thus, further investigation is needed to explore the interaction of visual information strategies and the mental modeling of dynamic systems that operate in non-pre-deterministic, non-linear sequences.

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Important Note