Technological tools for visual thinking: What does the research tell us?

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Abstract Educational systems tend to emphasise the verbal, symbolic and numerical modes of learning though recently, there has been a wave of change in education, with an increasing emphasis on visual literacy. In everyday life and in learning, visual information is used to interpret experience and build understanding. This can be illustrated in three ways. First, visual thinking is part of the way we reason, such as when we extract of information from a map, chart or table and represent and express it in language. Second, visual thinking can be integral to problem solving, as when we need to use a diagram to explain, document, calculate or show the steps involved in reaching a solution. Third, visual representation can play a role in communication, for instance using diagrammatic and visual forms to communicate information, represent data and show relationships. This paper aims to give an overview of current theories and research on visual thinking and how it relates to learning. Examples of how technologies can enhance the visual dimension of communication and learning are discussed.

Defining visual thinking

Is a picture worth a thousand words? It seems so, as historical accounts of scientific discovery and invention have shown that visualisation is a powerful cognitive tool (Rieber, 1995). The term visualisation is familiar to us from common usage and fundamentally means 'to form and manipulate a mental image'. In everyday life, visualisation is essential to problem solving and spatial reasoning as it enables people to use concrete means to grapple with abstract images. The process of visualisation may simply entail the formation images, with paper and pencil or even mentally, to investigate, discover and understand concepts, facts and ideas.

The original meaning of the Greek word for "to prove" in Mathematics, (*deiknumi*) was *to make visible or show*, indicting the close link between demonstrating understanding and having the capacity to show or draw a proof. However, the world of mathematics teaching has oscillated between periods when visualisation was regarded as important in pedagogy and eras when it was viewed as hindrance. Practices in mathematics problem solving are often based on linguistic representations that make use of logical connectives in sequential reasoning. Recent research in mathematics teaching (Diezmann, 1997) however has advocated the use of diagrammatic explanation to assist comprehension. Pictorial and visual forms of representation can offer advantages over text-based resources by offering scope for:

- displaying spatial interrelationships;
- demonstrating proportional relationships within and between objects;
- facilitating perceptual inference (eg, relative size of objects)

In addition, visualisation has achieved huge successes in helping scientists and mathematicians to understand and present their research (eg Gleick, 1987; Cunningham 1994; Klotz, 1991).

In this paper, it is claimed that:

- visual forms of representation are important, not just as heuristic and pedagogical tools, but as legitimate aspects of reasoning and learning;
- the technologies can offer visual experiences which foster higher order cognition;
- students should be encouraged to use multiple modes of representation when learning with technologies.

In his review of literature on cognitive tools, Mike Graves (1993: 2) of *Learning Technology Group, Apple Computer* emphasises that "in order to accomplish complex cognitive tasks, we invent tools, which in turn influence and contribute to the design of ways in which we think, which enables us to invent further tools to accomplish more complex cognitive tasks on so on, in reciprocal, mutual design". The paper elaborates on this view and provides a case study as an illustration.

Visual thinking and visual literacy

The ubiquity of visual messages surrounding our need to process visual information, has led to an emerging movement for development of visual literacy skills and spatial abilities (Mohler, 2000). The case is explained by Seels (1994, p. 99) as follows:

With visual literacy — the ability to both understand and make visual statements — we become sensitised to the world around us, the relationships and systems of which we are a part. Visual literacy integrates personal experience and imagination with social experience, technology and aesthetics.

There is an extensive literature on the application of visual literacy skills and knowledge in improving the teaching and learning process. Some examples are the use of mind mapping and concept mapping as learning strategies (Buzan, 1996), and the use of dynamic visual support through multimedia to assist language comprehension of short stories (Sharp, Bransford, Goldman et al. 1995).

Visual aspects of cognition are also recognised as important in instructional design. Research on textbook design by Mayer, Steinhoff et al. (1995) found that when illustrations were placed alongside texts and contained annotated captions of the information from texts, students' recall and comprehension improved. This result was interpreted in the light of a constructivist theory of learning which posits that learning involves constructing connections between visual and verbal representations of a system.

Similar and related research on the benefits of mixed sensory mode instruction suggests that in some cases visual instructional formats can enhance learning. Cognitive psychologists working with a theory of cognitive load theory now acknowledge that more effective working memory processing capacity is available if learners work in multiple modes, such as text and graphics. Working with in this framework, Jeung, Chandler & Sweller (1977) predict that audiovisual factors will enhance learning only if cognitive resources are not required to relate audio and visual resources. In addition, students are more able to exercise thinking strategies as long as the computer and the user interface complement learning objectives, and do not distract the learner.

Differences between visual and verbal thinking

What is the relationship between visualisation and reasoning? Some theorists say we need to envision information in order to reason about it, communicate, document and preserve it (Tufte, 1990). Although visual images are part of human cognition, they tend to be marginalised and undervalued in education. If we consider the differences between visual and verbal forms of representation for instance, we can begin to see the constraints of a purely language based approach to learning. Table 1 shows some of the differences between visual and verbal modes of representation and what can deduced from this comparison is the capacity of visual representation to support learning and understanding by presenting multiple perspectives and engaging the learner in dynamic, non-linear modes of thinking.

Both visual and verbal experiences support knowledge construction, and a great deal of sensory learning is visual (Sinatra, 1986). On these grounds, opportunities should be sought in learning environments to exploit the visual mode of expression and thinking.

Verbal Representation	**Visual Representation**
May reflect temporal and logical relations among events and objects	Depicts spatial logical and typographical relations between objects or events
Arbitrary and sequential, ie based on semantic coherence	Non arbitrary: visual representation may resemble actual object and events
Linear, one dimensional exposition of ideas	Dynamic and continuous, can characterise multiple aspects of ideas and concepts

Table 1: Differences between visual and verbal representation

Educational systems tend to emphasise the verbal, symbolic and numerical though recently, there has been a wave of change in education. The visual literacy movement is, according to Avgerinou & Ericson, (1997) gaining considerable momentum, and is all encompassing concept that deals with the multiple aspects of intentional *visual communication*, for example fostering visual imagery and perception and using visuals for communication, thinking, learning and creative expression. Trends are converging in education and research to emphasise visual approaches which support learning, which have implications for technology-supported environments where students are often learning at a distance, or in the open learning mode. The incorporation of visual resources is evident in current Internet applications, with multimedia and telecommunications which support flexible and dynamic knowledge representation. The next generation Internet will be very high bandwidth, with very affordable costs. We are already experiencing the integration of voice, video and data. In addition, very powerful servers providing huge amounts of storage will increase the multimedia capabilities of the network.

Theoretical views of visualisation

One of the reasons why visual literacy has not yet achieved a sound theoretical basis is that it is not a construct with operational specificity, nor is it a discipline or profession (Seels, 1994). Adding to the complexity of the term, there several theoretical accounts of visual literacy.

Visualisation has been accounted for by a number of theorists who have indicated its centrality in reasoning and learning. Bruner (1984, p. 99) characterises two alternative approaches to solving problems, one being intuitive, the other analytic.

> In general intuition is less rigorous with respect to proof, more oriented to the whole problem than to particular parts, less verbalised with respect to justification and based on confidence to operate with insufficient data.

Some psychologists relate different modes of thinking to different hemisphere of the brain, the "metaphorical left and right brains" where the right is home to the visual, spatial, and analogical, and parallel processing capacities, while the right is verbal, linear, sequential and logical. The location of the different modes of thought is not as important as the distinction between intuitive thought processes and logical thought processes. For learning, integration of the two modes of processing would seem the best approach; appealing to the right brain to make global linkages and to the left brain to build logical relationships. Much current research has focused on the undue emphasis given to sequential logic, and current theories of higher order thinking have endorsed a definition of higher order thinking which includes both creative (intuitive) and logical reasoning components (eg., Paul, 1993; Sternberg, 1985).

In support of the notion of multiple forms of reasoning, several prominent theorists have rejected the notion that verbal communication is the most important means of representing and constructing experience. Gardner (1994) speaks of the theory of 'multiple intelligences', but argues for the special status of visual-spatial intelligence in contrast to verbal intelligence. Other theorists who adopt a social perspective on learning (eg., John-Steiner, 1995) propose the idea of *cognitive pluralism,* or varying sense modalities, to emphasise the multiple modes an practices that are available to generate, communicate, learn and display knowledge. This interpretation of visual thinking sees it as a form of action, a social activity through which learners can interpret and transform their own thinking.

Cognitive apprenticeship models of learning (eg, Collins, Brown & Newman, 1989) are related to the notion of cognitive pluralism, or the use and application of a variety of experiential modes in learning. The recognition that learning is a means of increasing participation in 'communities of practice' is based on the Vygotskyan notion of learning as activity (Rogoff, 1990, McLoughlin, 1999). Increasingly, there is a focus on integrating perspectives from the cognitive and social sciences to develop situated theories of learning where active participation in a social context or in authentic practice (Lave & Wenger, 1991) has redefined the nature of expertise and learning. A range of processes and experiential tasks envisaged by the cognitive apprenticeship model can be mediated by computers. For example, representation of expert knowledge and externalisation of thinking processes can be achieved by offering students multimedia learning tools. Conventional learning systems have relied heavily on verbal and symbolic modes of teaching, but recently there has been evidence that cognitive apprenticeship forms of learning, which emphasise participation, modelling and authentic activity are informing the design of multimedia learning tools (eg, McLoughlin & Oliver,1998). The multimedia tools enable the learner to experience, observe and participate in activities which would otherwise be out of reach or not possible in formal learning contexts (eg Whalley, 1995).

Visualisation and changing paradigms of learning

The visual representation of ideas is just as much a part of the learning process as using language and other symbolic representations, yet current theories of learning with technology do not always highlight this important dimension of the learning process. Theorists have emphasised that visual thinking is a fundamental and unique part of our perceptual processes and that visualisation is a partner to the verbal and symbolic ways we have of expressing ideas and thoughts.

To what extent does current educational practice utilise visual resources to enable individuals learn more effectively? The pedagogical function of visual resources has usually been associated with their motivational qualities, for the scope they has to substitute for direct experience by presenting objects and events that are beyond the daily experience of the learner. Today's graduates require both visual and verbal thinking skills and need explicit practice in representing, interpreting and manipulating the visual aspects of their knowledge in multiple forms.

Rieber (1995) gives an interpretivist overview of how visualisation and imagination lead to scientific and mathematical generalisation. He concludes that "we can turn to almost any object within our reach into a tool for visualisation". Multiple visual modes of thinking, varying in style and formality have characterised thinkers drawn from a variety of domains. Writers use generative notes to trigger imagery while sketches and jottings are a familiar way to note down thoughts a that are later expanded, showing that the condensed private thinking that individuals do must be expanded and elaborated for communicative purposes. Computers have the potential to support cognition, to be used to extend intelligence. Interesting examples of these uses have been found where computers are used for a variety of purposes, to enhance both visual and linguistic aspects of learning (Klotz, 1991; Hoyles, Sutherland & Healy, 1991).

Rieber (1995) argues that the instructional materials should enable visually oriented problem solving approaches and generate multiple representations, rather than confine the learner to abstract visual strategies. Salomon (1997) reinforces this view, suggesting that if education is concerned with merely transmitting actual knowledge, then a chalkboard is probably the right technology. Computer visuals and simulation tools provide objects and representation, to model and activate cognitive processes. Primarily, these representations are visual, ie symbols, pictures, graphics, simulations and animations. These visual and sensory modes of teaching and learning with computers can achieve what Salomon & Globertson (1991) have called a "cognitive residue" where there is improved cognitive ability, for example, in self-regulation and mindfulness.

In many disciplines, like mathematics and physical sciences, visual-spatial approaches have been dominant for some time (Zimmerman & Cunningham, 1991). In arguing a case for other forms of reasoning other than deductive inferences, Barwise & Echmedy, (1991) have emphasised the importance of visual non-linguistic inference. Some theorists are often sceptical about such reasoning as it is intuitive and does not have the sophistication of the semantic basis of linguistically based reasoning. Nevertheless applications of technology to support visual and spatial reasoning continue to grow.

Information technology and visual learning

Telecommunications and technologies connect people in a range of different locations and enable them to share visual images, text and graphics and communicate by voice and text based messaging (Mason, 1994). In Western Australia, desktop videoconferencing and audiographic conferencing are used to connect learners in remote areas and to deliver curricula to students living in rural and isolated areas. Using Macintosh computers loaded with the software *Electronic Classroom,* students can create and share graphics while communicating with students at other remote sites in what has become an "extended classroom" model of education (Burge & Roberts, 1993; McLoughlin et al, 1997).

Observations of these classrooms show that telecommunications can expand the educational process and enhance the visual/sensory mode of communication among students who access the curriculum via telematics. One of the characteristics of telematics classrooms is that the computer can be used to share visuals and graphics. The screen can provide a number of interactive support for learning:

- immediate feedback to students when used as a blackboard;
- visual stimulation;
- a flexible, editable page;
- shared reading and writing;
- and record of written work that can be saved and printed.

In telematics classrooms, the technology can, when used appropriately, be used to promote higher order thinking outcomes, (Oliver & McLoughlin, 2001). However, the reliance on verbal communication can sometimes tend to diminish the effects of how visual presentation of images, such as graphs, charts and concept maps, (which are means of informing and supporting learning) support distance learners. So far, little research has focussed on how such visual and expressive means can foster thinking and reasoning processes. Graves (1993) draws attention to the ways in which design of visual tools support cognition, differentiates experiential from reflective cognition. The former includes recognition of situations and meanings, and experiences of the here and now. Tools for reflective cognition, on the other hand, foster analysis, synthesis and metacognitive awareness. Similarly, Norman (1993) believes that reflective learning had been shortchanged and that we have tended to value entertainment and experience over reflection. For example, television is a more popular medium for experiential learning than academic textbooks, but does not support reflection.

The following case study of distance learning classrooms using audiographic conferencing provides initial insights not only into teaching and learning in these environments, but also considers the role of graphics tools available to students to support visual representation of ideas and reflective learning.

Visualisation in the electronic classroom

In 1996, The Education Department of Western Australia (EDWA) decided to expand its curriculum delivery via telematics, to enable academically gifted students in rural and remote areas to access the curriculum via audiographic conferencing. This project offered an opportunity to observe first hand how students utilised the technology to support communication, visual thinking and higher order learning (McLoughlin & Oliver, 1998).

Telematics classrooms are asynchronous learning environments where verbal communication is achieved via a two-way audio-link. Documents, diagrams, drawings and pictures can be sent between computers via the telephone lines. In this real time environment visual tool combined with two-way audio can support dynamic exchange of ideas and information. In telematics classrooms, the teacher is not physically present in the classroom, and with the lack of gestures, cues and facial expressions, there is a consequent reliance on oral and verbal means of communication. Laurillard (1995) characterises such environments as 'discursive', as they enable interactive voice links through asynchronous communication while providing a shared, adaptable visual focus through use of computer technology.

Typically, a teacher would have a distributed classroom spread over several sites, with 3-6 students at each site. Interaction and communication between sites is achieved via the audio link and the computer which is used as an interactive whiteboard. Using the software "electronic classroom" the teacher can interact with students in geographically dispersed areas. Students have at their disposal a keyboard and graphics tablet with which they can draw, write, present and display visual representation of ideas. Each student can share his or her work, and the teacher can view the strategies used by students as they use the drawing tools to display their ideas.

Several observations were made about the quality of learning in this environment, to assess whether the technology can support visualisation and articulation of ideas in non-verbal modes. In one classroom, students collaborated around the computer, and took turns successively adding to or modifying their understanding of mathematical concepts. The objective was to create a plan for a report they had to write on an investigation of the octagonal links they had been working on in class.

Students were encouraged to depict their ideas graphically, rather than writing essays or lists of words. As they shared ideas and discussed a starting point for a report on their investigation, the drawing tool was used to create a concept map to display ideas and show connections (Figure 1).

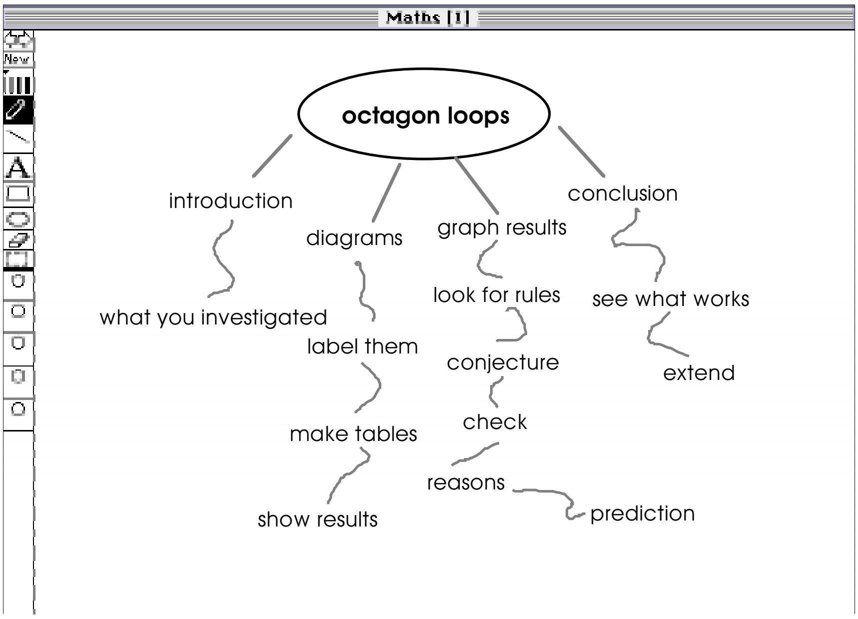

Figure 1: Concept map of octagon loops investigation created by students

This enabled students to display their own representation of the problem while talking about it and explaining it to students at other sites. The diagrams had a richness and complexity that was greater than a traditional text-based document, and was a mental model of how students perceived the investigation of octagon loops. The concept map was not only a collaborative effort, it later became a focus for discussion and led students to reflect, modify and refine their ideas. In this case the computer became an extension of mind, and the monitor a looking glass and support for thinking. In constructing their conclusions, students used language a means of articulating and expanding their understanding of how to investigate octagon loops. Language provided a means of expressing ideas, but it was the capacity to use the technology to create visual images and representations on the computer screen which could be revised, referred to and shared provided a more powerful means of assisting their cognition. Figure 1 provides an example of a concept map created by one group of students to represent their understanding of the mathematical concept of an octagon loop. The provisional and dynamic nature of the conceptual map also instigated reflection and discussion by students at other sites, and they reconstructed the information presented in the drawing to help them identify the main aspects of the topic.

Audiographics technology up to has been an under-utilised resource, largely because of the inherent limitations of the technology to support graphical representation for reasoning and generative thinking. In many distance learning settings, the technology mediates learning and communication, and has the potential to support discussion, adaptation, reflection and interaction, all of which are components of the learning process (Laurillard, 1995). In the classrooms observed these elements were present as students displayed their ideas, while they could also remodel and adapt them, gradually constructing new versions and depicting them visually, as a means of expressing their own understandings and creating new knowledge.

Observation of the learners using the drawing tools while they interacted showed that they moved through a continuum from visual thinking through visual learning, to visual communication (Figure 2).

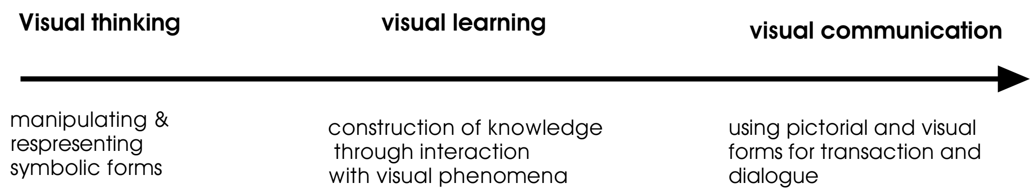

Figure 2: Continuum of visual thinking

This progression, from manipulation of visual forms, to construction of knowledge through interaction with visual representations, culminated in the sharing and communication of these ideas, in both visual and verbal form, to other students in the extended classroom. When learners collaborate in geographically isolated sites, using the telematics software, their verbal interactions initiate conversations but it is the act of representing these thoughts that leads to extension and amplification. The visual tools enable students to display ideas, open them to multiple interpretations and them revise them in the light of feedback from peers. These processes of exploratory dialogue are part of the process of higher order thinking (Mercer, 1996), while the visual dimension of experience and expression is an integral part of the verbal reasoning that occurs. This is an example of how in telematics environments, technology mediates the learning process and offers support for visual thinking

Conclusions: visualisation tools in telelearning

Telecommunications and computer tools can support the dynamic nature of reasoning, by supporting dialogue and articulation of ideas in multiple forms. In the telematics classrooms observed, the software tools allow dynamic expression of ideas in visual form, and is provides a powerful means of collaborative knowledge building. These preliminary findings suggest another dimension to learning in telematics environments. For learners in a distributed classroom who participate in synchronous audio communication, the expressive and visual mode of representing information and understanding can play a critical role in learning and reasoning. The software tools and the computer screen can serve as a *scaffold* or support for dialogue, reflection and learning, becoming in effect "cognitive tools" for learning (Jonassen & Reeves, 1997; Lajoie & Derry, 1993; McLoughlin, 1999).

These observations, though limited, underline the current research in many areas calling for students to have multiple skills and forms of expression that include the capacity to understand and convey information visually (Greeno, 1997; Salomon 1997). Increasingly, learning must take into account the range of symbolic and visual forms that enable construction, analysis and refinement of ideas. In telepedagogy, where teachers are at a distance from students, visual and discursive media can support the learning process by enabling active participation, while encouraging dialogue and construction of knowledge by students. One of the most promising technologies currently in use for increasing student spatial ability is VR technology, which provides interactivity aimed at enhancing human cognitive abilities. One of the most successful video-based VR technologies is QuickTime VR (QTVR) which is an extension of Apple's QuickTime (QT), which can generate three-dimensional models to improve visualisation ability. Learning enhancement is achieved by providing learners with tools and activities where meaningful relationships between concepts can be explored both verbally and pictorially, so that visual thinking progresses to visual communication, which is at the heart of long-term learning achievement. As educators we must therefore be aware that technological tools to support visualisation and representation are currently available and that Apple Technology is a major provider in the field.

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