How Humans Process Visual Information: A focused primer for designing information

Lou Tetlan and Douglas Marschalek

Abstract

Data is presented identifying a major gap between two-dimensional (2D) communication modalities and actual learning of its content. It is proposed that information designers can create formats that are cognitively more effective by incorporating constructs from the cognitive sciences. In order to effectively design information for learning, an understanding of how the brain processes information is important and presented. In addition, application of cognitive constructs have the potential to guide designers in creating cognitive-based information designs (CID). Seven cognitive constructs are discussed that can directly impact the effectiveness of information formats.

Keywords

Communication, Cognitive-based Information Design (CID), information design, information processing, reading

Introduction

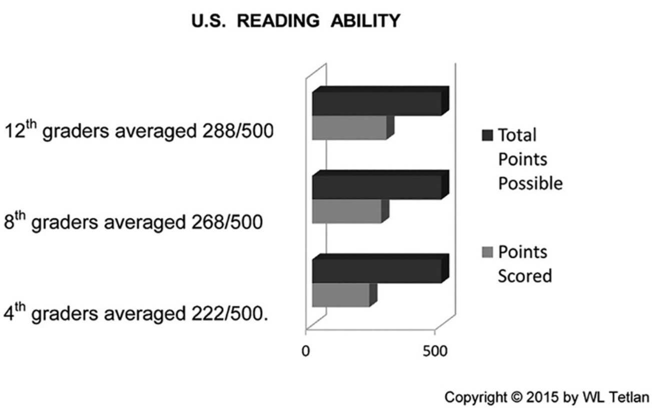
The ability to develop and understand written communication is a hallmark of human ingenuity. Over time Western cultures moved from simple scratches to pictorals and complex symbol systems that emerged as alphabets. As time progressed, written communication in the Western world became more dependent on forming words [text] with alphabets. Apparently word-forming alphabets provided needed clarity to symbol and image-based messages. (Dehaene, 2009)

The Gutenberg press and other tools for mass production of communication made text-based communications easier to create thus providing the vehicles for text to become increasingly dominant. In other words, Western communication became more reliant on text-based presentation of key concepts while images and symbols became less dominate.

At first, only selected populations were taught to read text. Today however, the majority of people in the Western world are taught how to read text. Since reading text is not an innate human ability such as walking or talking, special training is required. Statistics show that some people learn to read text easier than others. (See *figure 1*)

Figure 1

NAEP reading scores.



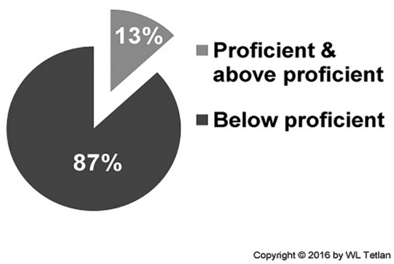
According to the 2013 National Assessment of Educational Progress (NAEP) report many U.S. high school students cannot read above 5th-grade level and 25% of seniors score below basic reading level. As shown in Figure 1, U.S. students scored well below the total 500 points possible within each grade level tested. During a similar period, an international comparison of students using a 1000 point scoring total, showed that U.S. students' average reading score was 498/1000 points, ranking the U.S. 20 out of 21 countries tested. (NAEP, U.S. Department of Education, 2013.) These statistics indicate the U.S. education system has a major communication challenge in teaching reading literacy that needs to be further addressed.

Among those who can read text, statistics show that some understand text content better than others. The question is: What percentage of people in the U.S. can both read text and accurately understand its content? In other words, how many people are estimated to be proficient in reading literacy?[1]

Data from the U.S. Department of Education, National Center for Education Statistics' publication *The Condition of Education 2014* (NCES 2014-083) indicate that only 13% of adults were at or above *Proficient* in reading literacy. Conversely stated, 87% of adults rank *Below Proficient* in literacy ability. (See *figure 2*)

Figure 2

Adult literacy percentiles.



In this study literacy was defined as being able to use "… printed and written information to function in society, to achieve one's goals, and to develop one's knowledge and potential." The study identified 4 levels of performance:

"Below *Basic*, *Basic*, *Intermediate*, and *Proficient*…13 percent of adults were at or above *Proficient* (indicating they possess the skills necessary to perform complex and challenging literacy activities) in 2003." (NCES 2014-083)

Therefore, the number of readers in the U.S. who have difficulty reading or correctly interpreting text represents the majority of the adult population. It is a sad irony - at a time when our culture is being inundated with information – that the majority of U.S. citizens may have difficulty or can not properly interpret or correctly understand what they are reading. This poses a pivotal challenge to professionals whose job it is to effectively convey information using text.

Investigating Text Formats

Any number of variables could be contributing to this situation. Upon a review of research addressing this topic, it became apparent that com-

1 In this article 'reading comprehension' is defined as comprehending individual words and units of meaning while 'reading literacy' is the ability to transfer and understand how that knowledge fits into the larger arena of daily life.

paratively few scientific studies have focused on how information is being formatted for authentic, or everyday real-world, materials used for transmitting information.

Existing experimental cognitive research that has been applied to information design is often simplistic in form and not parallel to the complex imagery of learning and daily life. For example, one such stimulus was comprised of tilted T's, L's, X's and sideways T's placed among upright T's (Beck, Jacob 1974). Subjects were observed as to how they discriminated like shapes. This type of format would not normally be seen in authentic formats of reading material. Another such example shows a shape that looks like an upper case H tilting backwards therefore presenting the top end points of the H closer together than the bottom end points (Solso, R. L. 1999). Interpretation of whether the symbol is an A or an H can be dependent on what letters are placed on either side of the tilting H. For example, is the word 'CAT' or 'THE'? This exercise demonstrates how the brain may interpret the same letter in different ways depending upon its context. These examples are both valid but do not reflect the type of materials read in real life situations. Therefore we chose to take a closer look at how the formatting of information in authentic applications might impact reading literacy.

After several years of researching this issue, we posit that the way information is formatted may be as important to literacy, or understanding the content, as the content itself. Additionally, we posit that in order to increase reading literacy, experimental studies are needed focusing on how the formatting of words, images, shapes, space, and symbols affect the processing of information using authentic materials.

We acknowledge the need and importance of reading text-based material and whole-heartedly support continued efforts in improving reading skills. We also acknowledge that there are specific forms of reading materials that require a predominantly text-based format. However, text-based materials are not the only format for presenting information found in manuals, brochures, textbooks, posters, or when the topic addresses such subjects as science, technology, engineering, mathematics, or procedural knowledge. We propose that there is a significant need for a broader range of formats that could enable the other 87% of the population to more readily access and understand written content in two-dimensional (2D) format. Two such formats are: 1) visual-based formats, and 2) cognitive-based formats.

Visual-based formats present information through a fluid reading format that incorporate words, images, shapes, space and symbols. These visual-based design formats are known by a variety of names including but not limited to, information graphics (Lankow, Ritchie & Crooks, 2012), information architecture (Wurman, 1997; Wurman, Whitehouse, Sume & Leifer, 2001) and visual language[2] (Horn, 1998; Tufte, 1997) . For simplicity

2 The terminology 'Visual Language' has varied meanings to different groups. For some, it means comic book and/or graphic novel language, for others manual hand sign language, and yet others use this terminology when describing infants looking at written words.

sake, in this article, we refer to these types of information design as visual language. These formats have become increasingly common in popular culture. However, predominantly text-based formats remain the standard vehicle for transferring information when using 2D formats.

Cognitive-based formats present information using constructs from fields of science. The fields of science and those fields applying experimental scientific research methodologies that we looked at included cognitive psychology, educational psychology, neuroEducation, neuroscience, science of human development, and ophthamaology. Formats based on cognitive constructs from these fields present information in ways that parallel how humans are thought to actually process information, build knowledge, and facilitate recall. Designing these formats entails following specific constructs using words, images, shapes, space, and symbols.

Designs for information constituting visual-based formats may also contain various cognitive constructs – be it a result of intention, good design, or intuition. However, the cognitive-based formats are created solely based on vetted experimental scientific research findings, using only cognitive constructs to guide how each variable (words, images, shapes, space, and symbols) is used. From a reader's viewpoint, the untrained person may not be aware of whether the format being viewed is visual-based or cognitive-based. However, for those trained in cognitive-based formats, the differences between the two types of formats are readily apparent. While researching which cognitive constructs could be valuable tools for designing information, we noted similar principles discussed in graphic design literature. A synopsis of cognitive constructs and the complementary graphic design principles are shown in Table 1. The first column identifies the cognitive trigger each construct influences. The second column identifies the cognitive constructs.[3] The third column identifies complementary principles from graphic design.

Background

The following discussion addresses each of the seven cognitive constructs listed in Table 1, indicating the role each has in designing formats. These constructs affect essential elements for learning that can influence attention, knowledge-building, and recall. These constructs were the first ones we vetted and do not constitute a complete list.

3 The authors associated with each cognitive construct and graphic design principles are representative of a longer list of names associated with each construct and principle. Due to limited space in a Table only a few names could be included.

Table 1

Triggers Affecting	Cognitive Construct	Design Principle
Attention	**Attentional Capacity** is limited. Requiring a reader to combine and process components of information within the same visual unit can lead to shortened engagement and poor reading habits. LaBerge & Samuels (1974).	**Information Design Principles** format content to stay within memory units by using Compositional Semantic Fusion. This fusion focuses on combining words, images and symbols in discrete units. Horn (1998).
	Split Attention – When readers have to visually seek, find and combine information from multiple areas, processing time can double and interfere with learning cores material. Sweller (1994).	**Continuity and Proximity** – When information is not where readers expect to find it, confusion can result. Harris (2007).
	Cognitive Overload occurs when short term memory cannot process information due to too many different pieces of information being presented together. Sweller (1994).	**Overload Amnesia** occurs when too much information tries to infiltrate the memory. Cognitive overload can occur along with loss of arbitrary data. Wurman (2001).
Knowledge Building	**Information Processing Models** identify how the brain takes in sensory information, uses short term memory to build knowledge, stores and recalls long term memory. Siegler and Shipley (1995).	**Percept-Concept Integration** combine percepts (objects shown as visual images) and concepts (mental ideas shown as text) for ease of comprehension, retention, retrieval. Horn (1998).
	Schema Acquisition – Human brains organize information according to meaning. Bartlett (1932), Rumelhart (1980), Sweller (1994).	**Hierarchy** groups and sequences information making it easier to understand relevance, priority and order, helping to establish meaning. Holmes (1984), Shedroff (2001), White (2002).
	Prior Knowledge provides an attachment for new information and cues as to how to transfer and use that knowledge. Bransford, Brown and Cocking (1999).	**Making Connections** – "Failing to make connections between the known and the unknown prevents us from grasping new ideas…" Wurman, 2001, p. 261.
Recall	**Theories of Expertise** suggest that experts chunk information into meaningful units of understanding to facilitate recall. Bereiter and Scardamalia (1993), Dhillon (1998).	**Chunked Information** clusters words, images and symbols into meaningful units of memory-compatible information. Horn (1998), Shedroff (2001).

Attention Factors

Attentional Capacity.

Humans have a limited attention span (Cowan et al,1999; Healey & Miyake, 2009; LaBerge & Samuels,1974; Muller & Rabbitt,1989; Neely, 1977; Pass, 1992; Pomplun et al, 2001; Posner et al,1980; Rosenthal et al, 2006) that varies according to type of activity and working memory capability (McVay & Kane, 2012). In order to understand communication it is necessary to remain engaged long enough with the material in order for the brain to make sense of what it is seeing. Brain imaging studies have shown that the brain works harder to make sense out of a word it does not know compared to a word it recognizes. The brain takes longer to identify unfamiliar words taxing our limited attention span.

In an effort to encourage readers to stay engaged with the material, using elements that can be interpreted more quickly than text, such as images and symbols, may prolong engagement. (Carney & Levin, 2002; Pelli et al, 2003; Horn 1998; Mayer &. Gallini, 1990; Mayer et al, 1996; Sweller, 2010.) Logic implies that longer engagement with content increases the probability of learning. When trying to teach someone about a new concept or procedure, speed of understanding the material may in turn contribute to further engagement. If new or topic-specific vocabulary is to be introduced in the material, it appears that these words may need to be introduced prior to seeing it in the context of the material in order to present information that is readily digestible; ready to be applied to prior knowledge and added to the readers vault of knowledge.

LaBerge and Samuels (1974) have stated that coordination of learner attention to the component processes of reading is crucial. If, for example, one component, perhaps decoding, requires too much attention, the limits of attentional capacity of the reader may result in poor comprehension or difficult-to-"cure" (non)reading habits.[4] (Chall, 1996) Therefore, the need for instructional material to capture readers' attention and keep them engaged is particularly important for readers who may need to be led into focused learning. Using cognitive constructs that have been scientifically proven to impact information processing may encourage increased engagement with the content presented. (Tetlan, 2013)

To date, text-based learning and information materials have primarily focused on the basic elements of language (e.g. word parts and types, sentence content and structure) with modest attention paid to the format and presentation of that content or the possible effect that format design might have on readers' overall comprehension. Current format of informational materials - e.g., manuals, worksheets, books, pamphlets - are often presented and structured in a primarily linear text format. In these formats lines of text consume the majority of the page and are tightly compact in a linear modality, creating the following:

- difficult to find information;
- the necessity for focusing on maintaining a long linear scanning sequence that disallows time for the brain to process the information;
- difficult to re-locate site of reading when the eyes momentarily shift from the point of reading.

Each of these can discourage continued engagement with the material. Based on what we now understand about the relationship between neural functioning, perception, and comprehension, it has become clear that these

4 According to Pugh et al (1997), 75% of third graders who are poor readers will still be poor readers in high school.

linear run-on formats do not mirror the neural functioning which directly impacts information comprehension, retention, and retrieval. (Dehaene, 2009; Horn 1998; Pelli et al, 2003; Sweller,1994,1989,1988.)

Another weakness of this format can be the placement of the image. Usually, the eye will be drawn to an image before text since the viewing capacity for shapes can be three times the size of capacity for viewing text.[5] (Mims, 2011) Therefore, placing an image to the right of text attracts the eye first to the image at the right, requiring the reader to visually backtrack to the left in order to read the text. This can weaken reader engagement due to limited attention span.

Split Attention

Split Attention refers to the necessity for readers to visually seek, find, and combine information found either on separate pages or in non-sequential areas of a single page that require physical/mental integration of the information in order to accomplish complete knowledge construction. (Ayres & Sweller, 2005; Levie & Lentz, 1982; Mandl & Levin, 1989) An example of this was found in a currently used text book that had images of an aircraft catching a space capsule while the text talked about propulsion, aerodynamics, structural engineering, Midas and Samos rockets, thrust, and military bases in England (Chester, 1960). The information in the visual images did not complement the information in the text of that page. However, the information relating to the images could be found on later pages, requiring the reader to seek out and combine the information.

Cognitive overload

Cognitive overload occurs when the brain cannot process what the eye is seeing due to receiving more cues than it is able to decipher. As discussed in more detail later in this article in the section on Information Processing, the brain can process only a certain amount of information at one time (3-7 items). When the incoming stimuli is more than the brain can process it can be overwhelming, encouraging disengagement with the material. (Sweller 1994; Moreno & Mayer 2000; Plass et al, 2003.) Sweller (1994) noted that the design of materials that considers "both intrinsic and extraneous cognitive load can lead to instructional designs generating spectacular gains in learning efficiency" (p.185). He further states that those designs causing extraneous cognitive load can be fatal to learning. (p. 226).

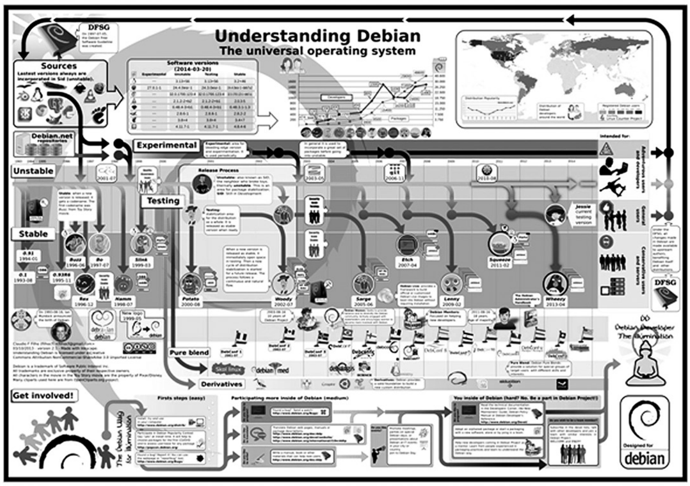
For example, Figure 3 illustrates how cognitive overload can occur when: the spacing of words, images and symbols are too uniformly spaced; there is no clear division of sub-topics (lack of chunking); no definitive hierarchy of information or identification of the 3-5 major points

5 Research into the human visual field indicates that we can clearly indentify shapes within a 30° range while text can only be clearly interpreted within a 5-10° range of the visual field.

to remember; and an overall high level of element interactivity. These are common problems with infographics. The example below is better than many infographics in its ability to guide patient readers through its use of symbols and color. For many viewers, this type of presentation of information contains too much information resulting in a type of brain freeze that discourages attention to the presented information. Attention is necessary in order for the brain to begin piecing the information together to gain understanding and build knowledge.

Figure 3

Example of Cognitive Overload.[6]



© 2013 by Claudio Ferreira

Another variable that leads to cognitive overload is Element Interactivity. This is an overuse of visual elements using lines, symbols, and color that are extraneous to the content. Any extraneous visual element, such as shadow boxes, can interfere with processing the intended content. Therefore, interactivity when not intrinsic to the content can impose a cognitive load that conversely interferes with learning. (Sweller, 2010).

The Cognitive Overload construct is important to the design of information. It basically states that the maximum load the human information-processing system can handle dictates the amount of information that can be successfully received. This suggests that designers reduce both the intrinsic and extraneous information in learning formats in order to limit cognitive overload. (Sweller et al, 1990) We can re-shape the design of information materials to reduce cognitive overload by:

- Deleting redundancies & using words concisely
- Grouping units of thought in spaces that the reader can visually take-in as a single unit of information

6 From Understanding Debian by Ferreira, Claudio, 2013 Infographic. http://cfnarede.com.br/infografico-do-debian. (Accessed November 5, 2015). Reprinted with permission.

- Limiting the number of fonts and colors used
- Balancing words with images, symbols and space
- Limiting the amount of lines and shapes used to only those that enhance understanding and flow of information.

Knowledge Building Factors

Information Processing Models

Information Processing Models provide a general framework for how information is processed. Information is perceived through our sensory organs (sight, hearing, touch, taste, smell). In this model, human brains have a capacity to hold 3-7 units of information at a time for a duration of 0.5 to 3 seconds. Those units that are captured and deemed relevant proceed to the brains working memory areas. Working memory can be maintained, in general, for 5 to 15 seconds. It is during this time that the brain is attempting to make sense of the units. In order for that to occur the brain will either attach the units to some form of prior knowledge or deem it irrelevant and proceed to delete the unit/s. Those connections made need to be repeated and rehearsed in order for that information to be encoded for longer-term memory.

Studies looking at the memory aspect of information processing reinforce that the brain spends only limited time in deciding whether the perceived units of information are important enough to pass on to working memory. Therefore, logic implies that units of information that take less time to decipher and provide clarity of relevant meaning are more likely to make it to the coding and recoding stages (working memory). This is one reason why pertinent images facilitate the uptake of information over text which can take longer to decode and recode.[7] Therefore, currently designed instructional materials which emphasize text over visual forms of information, may present information in ways that can create cognitive overload thereby lessening opportunities to learn. (Sweller,1994; Mayer et al,1996; Mayer & Moreno, 2003; Song & Schwarz, 2008)

Research performed by cognitive psychologists on methods of visual instruction suggests the potential for integrating visual-based interventions in learning acquisition. These cognitive psychologists include: Holley and Dansereau (1984) - effects of spatial elements on learning; Waddill, McDaniel and Einstein (1988) - inter-relationships of text and illustrations; Weidenmann (1989) - difference between effective and ineffective illustrations; Winn (1987) - effective use of diagrams, charts and graphs in learning materials; Carney and Levin (2002) - scoured decades of research and concluded that “Pictorial illustrations still improve students’ learning

7 See Neuroscience and the Physiology of Reading later in this article for more detail on reading text.

from text" (p. 5); and Mayer and Moreno (2003) - addressed the processing of pictorial materials.

Decades of research by both psychologists Richard E. Mayer and John Sweller, give strong support to the need for materials to be designed for learning and not just for presenting information. Their separate and numerous studies have looked at cognition, working memory, and instructional designs. In research by Sweller pertaining to computer training manuals, one user group was given the traditional manual which required readers to split their attention between the manual, a video screen, and their keyboard while a second group was given modified manuals containing the pictures and image of a keyboard all visually located on one page. The results showed the group with the modified manuals took less time to learn the subject, scored higher on a test about the program, and displayed higher accuracy skills applying the program than the group using the traditional formatted manual.

Sweller summarized the relationship of formats for learning by noting that—

- (a) Schema acquisition is a major learning mechanism when dealing with higher cognitive functions; they are designed to circumvent our limited working memories while encouraging our highly effective long-term memories.
- (b) A limited working memory makes it difficult to assimilate multiple elements of information simultaneously.
- (c) Under conditions where multiple elements of information interact, they must be assimilated simultaneously.
- (d) A heavy cognitive load is imposed when dealing with material that has a high level of element interactivity.
- (e) High levels of element interactivity and resulting cognitive loads may be caused both by the intrinsic nature of the material being learned and by the method of presentation.

(Sweller, 1994, 185)

Similar studies have been performed since Sweller's study that reiterate elements of his findings. (Brünken et al, 2003; Clark & Mayer 2003; Mayer 2002; Pollock et al, 2002; Mayer & Moreno, 2003.) These points illustrate the need to design information with cognition in mind. This includes presenting information in smaller chunks, or schemas that the brain can easily assimilate for long term memory.

Schema Acquisition

According to the developmental psychologist Jean Piaget (1958), a schema is a cognitive process whereby humans link incoming information to previously established units of similar information. It can be simple or elaborate. As new information is added to a previous schemata, that schemata becomes more complex. Schemata can be visualized as building blocks of knowledge. They organize information according to meaning, and thereby chunk the meaning of the information in ways that scaffold, or help build, understanding. Therefore, the redesigning of learning material that incorporates meaningful schemata could be essential to presenting stable chunks[8] of information thereby increasing accuracy of learning.

Also linked to schema acquisition are other elements of design. Mayer and Gallini (1990) noted that theories of mental models (de Kleer & Brown, 1985; Gentner & Stevens, 1983; Kieras & Bovair, 1984; Larkin & Simon, 1987; White & Frederiksen, 1987) support two elements of illustrations, *system topology* and *component behavior,* that enable learners to "build runnable mental models" (p. 715). System topology identifies the components and labels them; component behavior identifies the components and how they change, naming the parts, steps and sequences. According to cognitive psychology then, instructional materials that identify the components being discussed with labels while showing the steps of changes or movement, their names and sequences of the concept being taught, could provide improved learning tools and more effective transfer of information.

Neuroscience and the Physiology of Reading.

Understanding how information is processed through the eye-brain continuum provides a context for why properly designed materials could be a key factor in learning and improving reading literacy. The following section provides a discussion on the eye; how it transports what it sees (stimuli) to the brain; and what the brain does with that data in order to be able to interpret the stimuli. If the way we are designing information is contrary to the processes of the eye – brain continuum, then perhaps knowing this, can influence creating designs that are better aligned with how the brain actually processes information.

This discussion starts at the beginning of perception - with the way we see.[9] Since the mid-1900's neuroscience researchers such as Roger Sperry (1968, 1974, 1986) and S.M. Kosslyn, J. D. Holtzman, M. J. Farah, Gazzaniga, M.S. (1985) have used brain- imaging techniques to examine how adults perceive the world. Research on human perception, especially in areas concerning the functioning of the eye and brain in the perception of information, is quite well understood. (Fanf & He, 2005; Hubel & Wiesel, 1962; Kreiman et al, 2000; Dehaene, 2009; and Batterink & Neville, 2013)

The first level of processing visual information is in the retina. Stimuli from the viewed information travels through the optic nerve via the

8 Stable chunks of information combine elements in ways that leave little room for misinterpretation of meaning. Unstable information allows the reader to arrange meaning according to the reader's discretion and not necessarily according to the intended meaning.

9 This is a literal reference to 'seeing'. Although blind people can read by 'seeing' through touch, 'seeing' in that context is considered to be figurative. However, recent brain research indicates that it is quite plausible that through the sense of touch, blind people actually can see the word in their brain.

lateral geniculate or superior colliculus. The next level of processing occurs within the brain itself. However, "(w)hereas, the eye processes information sequentially, the brain is thought to do so in parallel operation". (Solso, 1999, 26) From the optic nerve, information "…is relayed 1) to the amygdala in the limbic system, for emotional analysis, and 2) to the visual cortex, two credit-card-sized areas in the occipital lobes…" (Sylwester, 1995, p.62)

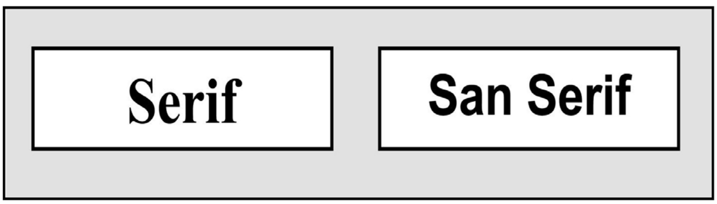
"The visual cortex responds to different stimuli in different areas of the cortex..." (Hubel & Wiesel, 1965, 1979.) In Hubel's (1963) words "Each cell seems to have its own specific duties; it takes care of one restricted part of the retina, responds best to one particular shape of stimulus and to one particular orientation." It processes the neural information into simple forms and shapes (Solso, 1999, 38) which are analyzed

> "…according to primitive features, such as vertical and horizontal elements, angles, and curves (which) are 'recognized' and 'classified' and dispatched to other parts of the brain…" (Solso, 1999, 6). The purpose of this is "…for higher order processing which requires the neuron messaging to be combined with previous knowledge for further interpretation"
> (Solso, 1999, 30). (McClelland & Rumelhart, 1981; Dehaene, 2009; Friederici, 2011)

One element that needs to be visually deciphered while reading are words and the letters that make up those words. Due to the importance of limited attention span a valid question is, which font type is more efficient for the visual cortex to decode? Serif or san serif?[10] (See *figure 4*)

Figure 4

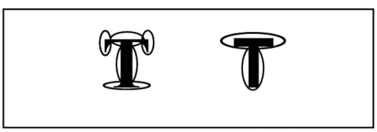
Example of serif and san serif fonts.



Serif fonts have extraneous decorative elements added to the vertical and horizontal structure of the letterform whereas san serif fonts do not. (See Figure 5.) Because the brain needs to tease apart each line of a letter, it therefore reasons that more time and effort are required for the brain

Figure 5

Lines in a font.



to interpret serif fonts than sans serif. (Pelli et al, 2003; Wogalter et al, 2005.) For instance, as seen in Figure 5, a serif 'T' has five lines to decode while a sans serif 'T' has only two. For example, the following sentence is presented first in a serif and then a san serif font:

10 'Serif' comes from the Dutch word schreef meaning 'line'.

The little red fox turned pink when feeling shy.

[serif example]

The little red fox turned pink when feeling shy.

[sans serif example]

When each of the letters in the serif font are broken down into individual lines, the sentence is found to contain 146 separate lines that the visual cortex needs to decode. Below is the serif sentence with corresponding numbers beneath each letter representing the number of lines each letter has to decode. In comparison, the same sentence using a sans serif font contains only 77 lines to decode. (See *figure 6*)

Figure 6

Counting letter lines in fonts.

The little red fox turned pink when feeling shy.
5 5 2 342232424 31 6 2545 24 4457 7525 4223454 355 = 146 lines

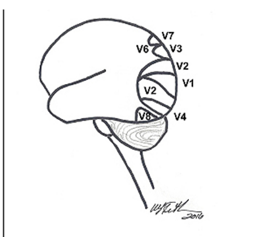
The little red fox turned pink when feeling shy.
22 2 122212 222 212 222222 2223 4222 2221223 122 = 77 lines

Therefore, in theory reading the sans serif font would be more efficient than reading the serif font thereby consuming less of the readers limited attention span. In this case, the sans serif sentence is nearly twice as efficient to decode than is the sentence using the serif font. These statements are based on logic. Actual text reading performance depends on the interaction of many factors including font familiarity.

When stimuli reaches the visual cortex, the brain sorts the cues into categories. Rita Carter (1999) summarizes the identified areas of the visual cortex as follows (see Figure 7): "... V1 – general scanning; V2 – stereo vision; V3 – depth and distance; V4 – colour; V5 – motion; V6 – determines objective (rather than relative) position of object; 'Where?' path: V1-V2-V3-V5-V6; 'What?' path: V1- V2 - V4." (p.112.)

Figure 7

'V' locations in the brain.[11]



Other studies have focused on the ways in which perceived information is configured in the brain with attempts to document the loci

11 V5 deals with motion and not the processing of 2D reading materials and therefore is not included.

of specific activities. (Kreiman et al, 2000; MIT, 1996; Roska & Werblin, 2001) These studies indicate that there is a difference in loci between reading words and making sense of them. In addition, when viewing a word the brain engages eight different processes in order to understand it's meaning: phonological processing; subvocal articulation; word meaning; color perception; making grammatical judgment about word gender; syntactic (sentence-level) processing; suppression of lexical properties of written words; and word-level orthography (visual word form) processing. This entire visual process, from the time stimuli enters the eye until the brain makes sense of it takes less than 1/3 of a second or c. 300 msec (Solso, 1999, 34). This is an initial perceptual response to visual stimuli that triggers higher order cognitive processes resulting in more complex meaning making. (Hempenstall, 2006; Kamitani & Tong, 2005; Richards, et al 2006)

Prior Knowledge

Prior Knowledge refers to that knowledge already stored in long term memory. In order for new information to obtain meaning, it needs to attach itself to prior knowledge. Therefore, if the new information is to be attached to the correct unit of prior information, designs need to include some trigger that evokes that prior knowledge. Providing links that activate prior knowledge have shown an increase in learning. (Gurlitt & Renkl, 2010; McNamara, 2001) Without triggers, the reader is left to evoke whatever unit of prior knowledge they think the new information should be attached to or deem it irrelevant and be dismissed. Presenting information without a link to the proper unit of prior knowledge is another form of presenting unstable information. This can lead to inaccurate understanding of the information, be it: a process to follow; the purpose of a product; or the place (unit) the information should be grouped with and stored. If the prior knowledge evoked is not compatible with the new information, prior knowledge may override the new information (Alvermann et al,1985; van Loon et al, 2013) resulting in non-effective transfer of information.

Ways to activate prior knowledge include, but are not limited to: discussion of topic prior to seeing new information; visuals that stimulate memory; written questions; and providing worksheets or visuals that require readers to link associated topics or sub-topics. (Schmidt et al, 1989; Pressley et al, 1992)

Recall Factor

Theories of Expertise

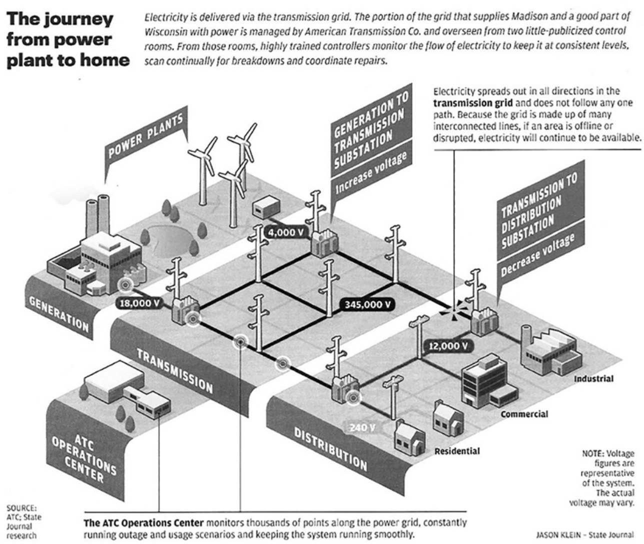
Theories of Expertise note that experts facilitate information retrieval (recall) by grouping, or chunking, information. (Bereiter & Scardamalia,1993)

Formats that visually chunk information scaffold a reader's ability to store information accurately and make long-term retrieval of that information more likely. Chunking information appropriately in a visual format "incorporates two or more elements into a single element, [and thus] reduces extraneous cognitive load and enhances learning" (Sweller, 1994, 193).

Figure 8 is an example of how information can be chunked into meaningful and easily digestible units of information. Notice how the overall visual image has been divided into 3 units. Each of these three major units are further divided into 3-4 units of information. A combination of words, images, symbols and space have been applied unifying the chunks. Lines and shapes were limited to only those that facilitated understanding and flow of information.

Figure 8

Example of chunking information.[12]



Conclusion

There are no templates for using the cognitive constructs discussed in this article. The final design will depend on: the topic; the viewers developmental age and anticipated prior knowledge; which 2D format is being used e.g., print, multimedia; and what the designer is attempting to achieve with the information.

12 From "The journey from power plant to home" by J. Klein, (2012) Wisconsin State Journal, Vol. 172 No.22, page A1. Copyright (2012) by the Wisconsin State Journal. Reprinted with permission.

Also, there are more cognitive constructs that apply to the processing of information than the seven constructs presented in this article. The seven selected have direct implications on how we present information for learning. Decades of research on how humans process information have provided us with insights into how the brain processes such information. Though there is much to be learned yet, we can begin to apply constructs that have been accepted by researchers and their respective fields in order to present information with better stability and clarity.

In this article we have proposed that formats designed using such constructs could be an important key to improving reading literacy and learning with effective transfer and retention of information. Design formats based upon these constructs have the potential to positively influence reading literacy for 87% of adults who rank *Below Proficient* in literacy ability (data from the U.S. Department of Education, National Center for Education Statistics' publication *The Condition of Education*.)

These constructs can serve as guidelines when designing visual information formats. Consciously applying relevant cognitive constructs to create units of graphic content that parallel how we process information may be the paradigm shift that could improve communication and facilitate transfer of stable information across a wider population of readers.

References

Alvermann, D. E., Smith, L. C. & Prior, J. E., 1985. Knowledge Activation and the Comprehension of Compatible and Incompatible Text. *Reading Research Quarterly*, Issue 20.4, 420-436.

Ayres, P. & Sweller, J., 2005. The split-attention principle in multimedia learning. In R. E. Mayer (Ed.), *The Cambridge handbook of multimedia learning*. Cambridge, Eng: Cambridge University Press, 135-167.

Batterink, L & Neville, H. J., 2013. The Human Brain Processes Syntax in the Absence of Conscious Awareness. *The Journal of Neuroscience*, Issue 33.19, 8528-8533.

Beck, Jacob, 1974. Relation between similarity grouping and peripheral discriminability. *Journal of Experimental Psychology*, Issue 102(6), 1145-1147.

Bereiter, C., & Scardamalia, M., 1993. *Surpassing Ourselves: An Inquiry into the Nature and Implications of Expertise*. Chicago: Open Court Publishing Company.

Bransford, J. D., Brown, A. L., & Cocking, R. R. (Eds.), 1999. *How people learn: Brain, mind, experience, and school*. Washington, DC: National Research Council.

Brünken, R., Plass, J. L. & Leutner, D., 2003. Direct measurement of cognitive load in multimedia learning. *Educational Psychologist*, Issue 38, 53–61.

Carney, R. N. & Levin, J. R., 2002. Pictorial illustrations still improve students' learning from text. *Educational Psychology Review*, Issue 14.1, 5–26.

Carter, R., 1999. Mapping the Mind. Berkeley and Los Angeles, CA: University of California Press.

Chall, J. S., 1996. *Stages of reading development*. Fort Worth, TX: Harcourt, Brace & Company.

Chester, M. & Kramer, S., 1960. *Discoverer: The Story of a Satellite*. New York: G.P. Putnam's Sons, 111.

Clark, R. C. & Mayer, R. E., 2003. *E-learning and the science of instruction*. San Francisco: Jossey-Bass.

Cowan, N., Nugent, L. D., Elliott, E.M., Ponomarev, I. & Saults, J. S., 1999. The Role of Attention in the Development of Short-Term Memory: Age Differences in the Verbal Span of Apprehension. *Child Development*, Issue 70.5, 1082–1097.

Dehaene, S., 2009. *Reading in the Brain: The new science of how we read*. New York: The Penguin Group.

deKleer, J. & Brown, J.S., 1985. A qualitative physics based on confluences. In D.G. Bobrow (Ed.), *A qualitative physics based on confluences*. Cambridge, MA: MIT Press, 7-83.

Dhillon, A. S., 1998. Individual Differences Within Problem-Solving Strategies Used in Physics. *Science Education*, Issue 82, 379-405.

Fanf, F. & He, S., 2005. Cortical responses to invisible objects in the human dorsal and ventral pathways. *Nature Neuroscience*, Issue 8, 1380-1385.

Friederici, A. D., 2011. The Brain Basis of Language Processing: From Structure to Function. *Physiological Reviews*, Issue 91.4, 1357-1392.

Gentner, D. & Stevens, A. L., 1983. *Mental models*. Hillsdale, NJ: Erlbaum.

Gurlitt, J. & Renkl, A., 2010. Prior knowledge activation: how different concept mapping tasks lead to substantial differences in cognitive processes, learning outcomes, and perceived self-efficacy. *Instructional Science*, Issue 38.4, 417-433.

Harris, R., 2007. *The Elements of Visual Style*. New York: Houghton Mifflin Company.

Healey, K. M. & Miyake, A., 2009. The role of attention during retrieval in working-memory span: A dual-task study. T*he Quarterly Journal of Experimental Psychology*, Issue 62.4, 733-745.

Hempenstall, K., 2006. What brain research can tell us about reading instruction. Learning Difficulties. *Australia Bulletin*, Issue 38.1, 15-16.

Holley, C. D. & Dansereau, D. F. (Eds), 1984. *Spatial learning strategies*. San Diego, CA: Academic Press.

Holmes, Nigel, 1984. *Designer's Guide to Creating Charts and Diagrams*. New York: Watson-Guptill.

Horn, R., 1998. *Visual Language: Global Communication for the 21st Century*. Bainbridge Island, WA: MacroVU, Inc.

Hubel, D. H., 1963. The Visual Cortex of the Brain. *Scientific American*, Issue 209. 5, 54-63.

Hubel, D.H. & Wiesel, T.N., 1962. Receptive Fields, Binocular Interaction and Functional Architecture in the Cat's Visual Cortex. *Journal of Physiology*, Issue 160.

Hubel, D. H. & Weisel, T.N. 1965. Receptive Fields and Functional Architecture in Two Nonstriate Visual Areas (18 and 19) of the Cat. *Journal of Neurophysiology*, Issue 28.2, 229-289.

Hubel, D. H. & Weisel, T. N., 1979. Brain Mechanisms of Vision. *Scientific American*, 150-162.

Kamitani, Y & Tong, F., 2005. Decoding the visual and subjective contents of the human brain. *Nature Neuroscience*, Issue 8, 679 – 685.

Kieras, D. E. & Bovair, S., 1984. The role of a mental model in learning to operate a device. *Cognitive Science*, Issue 8, 255-274.

Kosslyn, S.M., Holtzman, J.D., Farah, M.J. & Gazzaniga, M.S., 1985. A Computational Analysis of Mental Image Generation: Evidence From Functional Dissociations in Split-Brain Patients. *Journal of Experimental Psychology*: General, Issue 114.3, 311-341.

Kreiman, G., Koch, C. & Fried, I., 2000. Imagery neurons in the human brain. *Nature* Issue 408, 357-36.

LaBerge, D. & Samuels, S.J.,1974. Toward a theory of automatic information processing in reading. *Cognitive Psychology*, Issue 6, 293-323.

Lankow, J., Ritchie, J. & Crooks, R., 2012. *Infographics: The power of visual storytelling*. Hoboken, NJ: Wiley & Sons.

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

Levie, W. H. & Lentz, R., 1982. Effects of text illustrations: A review of research. *Educational Communication and Technology Journal*, Issue 30, 195-232.

Mandl, H. & Levin, J. R., (Eds.) 1989. *Knowledge Acquisition from text and pictures*. Amsterdam: Elsevier.

Mayer, R. E., 2002. *Teaching for meaningful learning*. Upper Saddle River, NJ: Prentice Hall.

Mayer, R. E., Bove, W., Bryman, A., Mars, R. & Tapangco, L., 1996. When Less is More: Meaningful Learning from Visual and Verbal Summaries of Science Textbook Lessons. *Journal of Educational Psychology*, Issue 88.1, 64-73.

Mayer, R. E. & Gallini, J. K., 1990. When Is an Illustration Worth 10,000 Words? *Journal of Educational Psychology*, Issue 82.4, 715-726.

Mayer, R. E. & Moreno, R., 2003. Nine Ways to Reduce Cognitive Load in Multimedia Learning. *Educational Psychologist*, Issue 38.1, 43–52.

McClelland, J. L. & Rumelhart, D. E., 1981. An Interactive Activation Model of Context Effects in Letter Perception: I. An account of basic findings. *Psychological Review*, Issue 88, 375-407.

McNamara, D. S., 2001. Reading both high-coherence and low-coherence texts: Effects of text sequence and prior knowledge. Canadian *Journal of Experimental Psychology/Revue*, Issue 55.1, 51-62.

McVay, J.C. & Kane, M.J., 2012. Why Does Working Memory Capacity Predict Variation in Reading Comprehension? On the Influence of Mind Wandering NS Executive Function. J*ournal of Experimental Psychology* Gen, Issue 141.2, 302-320.

Mims, C. 2011. Augmented Reality Interface Exploits Human Nervous System. *MIT Technology Review*. http://www.technologyreview.com/view/423575 (Accessed July, 14, 2015).

Moreno, R., & Mayer, R. E., 2000. A coherence effect in multimedia learning: the case for minimizing irrelevant sounds in the design of multimedia messages. J*ournal of Educational Psychology*, Issue 92, 117–125.

Muller, H. J. & Rabbitt, P. M. A., 1989. Reflexive and Voluntary Orienting of Visual Attention: Time Course of Activation and Resistance to Interruption. J*ournal of Experimental Psychology: Human Perception and Performance*, Issue 15. 2, 315-330.

National Assessment of Educational Progress (NAEP). 2013. U.S. Department of Education, Institute of Education Sciences, National Center for Education Statistics. https://nces.ed.gov/nationsreportcard/reading (Accessed January, 23, 2015).

Neely, J. H., 1977. Semantic Priming and Retrieval from Lexical Memory: Roles of Inhibitionless Spreading Activation and Limited-Capacity Attention. *Journal of Experimental Psychology*: General, Issue 106.3, 226-254.

Paas, F., 1992. Training strategies for attaining transfer of problem solving skill in statistics: A cognitive-load approach. *Journal of Educational Psychology,* Issue 84, 429-434.

Pelli, D. G., Farell, B. & Moore, D. C., 2003. The remarkable inefficiency of word recognition. *Nature*, Issue 423, 752-756.

Piaget, J., 1958. *Logic and psychology*. New York: Basic Books.

Plass, J. L., Chunb, D. M., Mayer, R. E. & Leutner, D., 2003. Cognitive load in reading a foreign language text with multimedia aids and the influence of verbal and spatial abilities. *Computers in Human Behavior*, Issue 19, 221–243.

Pollock, E., Chandler, P. & Sweller, J., 2002. Assimilating complex information. *Learning and Instruction*, Issue 12, 61–86.

Pomplun, M., Reingold, E. M. & Shen, J., 2001. Investigating the visual span in comparative search: the effects of task difficulty and divided attention. *Cognition*, Issue 81, 57- 67.

Posner, M. I., Snyder, C. R. & Davidson, B. J., 1980. Attention and the detection of signals. *Journal of Experimental Psychology*: General, Issue 109, 160-174.

Pressley, M., Wood, E., Woloshyn, V.E., Martin, V., King, A. & Menke, D., 1992. Encouraging Mindful Use of Prior Knowledge: Attempting to Construct Explanatory Answers Facilitates Learning. *Educational Psychologist*, Issue 27.1, 91-109.

Pugh, K. R., Shaywitz, B. A., Shaywitz, S. E., Shankweiler, D.P., Katz, L., Fletcher, J.M., Skudlarski, P., Fulbright, R.K., Constable, R.T., Bronen, R.A., Lacadie, C., Gore, J. C., 1997. Predicting Reading Performance from Neuroimaging Profiles: The Cerebral Basis of Phonological Effects in Printed Word Identification. *Journal of Experimental Psychology: Human Perception and Performance*, Issue 23.2, 299-318.

Richards, T.L., Aylward E, Berninger V, Field K, Parsons A, Richards A, Nagy W., 2006. Individual fMRI activation in orthographic mapping and morpheme mapping after orthographic or morphological spelling treatment in child dyslexics. J*ournal of Neurolinguistics*, Issue 19.1, 56-86.

Rosenthal, E. N., Riccio, C. A., Gsanger, K. M. & Jarratt K. P., 2006. Digit Span components as predictors of attention problems and executive functioning in children. Clinical Neuropsychology, Issue 21.2, 131–139.

Roska, B. & Werblin, F., 2001. Vertical Interactions across ten parallel, stacked representations in the mammalian retina. *Nature*, Issue 410.6828, 583-588.

Rumelhart, D. E., 1980. Schemata: the building blocks of cognition. In: R.J. Spiro et al. (Eds) T*heoretical Issues in Reading Comprehension*. Hillsdale, NJ: Lawrence Erlbaum.

Schmidt, H. G., De Volder, M. L., De Grave, W. S., Moust, J. H. & Patel, V. L., 1989. Explanatory Models in the Processing of Science Text: The Role of Prior Knowledge Activation Through Small-Group Discussion. *Journal of Educational Psychology*, Issue 81.4, 610-619.

Shedroff, N., 2001. *Experience design*. Indiana: New Riders.

Siegler, R. S. & Shipley, C., 1995. Variation, Selection, and Cognitive Change. In *Developing Cognitive Competence: New Approaches to Process Modeling*. Simon & Halford (Eds). Hillsdale, NJ: Erlbaum.

Solso, R. L., 1999. *Cognition and the Visual Arts*. USA: MIT Press.

Song, H. & Schwarz, N., 2008. If It's Hard to Read, It's Hard to Do: Processing Fluency Affects Effort Prediction and Motivation. *Psychological Science*, Issue 19.10, 986-988.

Sperry, R. W., 1968. Hemisphere disconnection and unity in conscious awareness. *American Psychologist,* Issue 23, 723-33.

Sperry, R.W., 1974. Hemispheric specialization: scope and limits in F.O. Schmitt and Frederic G. Worden (Eds.), *Neuroscience: Third Study Program. Cambridge*, MA: MIT Press.

Sperry, R., 1986. The new mentalist paradigm and ultimate concern. *Perspectives in Biology & Medicine*, Issue 29.3, 413-422.

Sweller, J., 1988. Cognitive load during problem solving: Effects on learning. *Cognitive Science*, Issue 12, 257-285.

Sweller, J., 1989. Cognitive technology: Some procedures for facilitating learning and problem solving in mathematics and science. *Journal of Educational Psychology*, Issue 81, 457-466.

Sweller, J., Chandler, P., Tierney, P. & Cooper, M., 1990. Cognitive load as a factor in the structuring of technical material. *Journal of Experimental Psychology: General, Issue* 119, 176-192.

Sweller, J. & Paul, C., 1994. Why Some Material is Difficult to Learn. *Cognition and Instruction,* Issue 12.3, 185- 233.

Sweller, J., 2010. Element interactivity and intrinsic, extraneous, and germane cognitive load. *Educational Psychology Review*, 22, 123-138.

Sylwester, R., 1995. *A Celebration of Neurons: An Educator's Guide to the Human Brain.* Alexandria, VA: Association for Supervision and Curriculum Development.

Tetlan, W. L., 2013. Applying Design to Learning: Cognitive Science Research Supports Visual Language Principles in the Design of Effective Educational Reading Materials. *DRS//Cumulus 2nd International Conference for Design Education Researchers, Vol. 2*, 829-845.

Tufte, E., 1997. *Visual Explanations: Images and quantities, evidence and narrative.* Cheshire, CT: Graphic Press.

U.S. Department of Education, National Center for Education Statistics, 2014. *The Condition of Education 2014* (NCES 2014-083).

van Loon, M.H. de Bruin, A. B., van Gog, T. & van Merriënboer, J.J., 2013. Activation of inaccurate prior knowledge affects primary-school students' metacognitive judgements and calibration. *Learning and Instruction*, Issue 24, 5-25.

Waddill, P. J., McDaniel, M. A. & Einstein, G. O., 1988. Illustrations as adjuncts to prose: A text-appropriate processing approach. *Journal of Educational Psychology*, Issue 80, 457-464.

Weidenmann, B., 1989. When good pictures fail: An information-processing approach to the effects of illustrations. In H. Mandl & J. R. Levin (Eds), *Knowing acquisition from text and pictures*. Amsterdam: Elsevier, 157-171.

White, A., 2002. *The Elements of Graphic Design.* New York: Allworth Press.

White, B. Y. & Frederiksen, J. R., 1987. Qualitative models and intelligent learning environments. In R. W. Lawler & M. Yazdani (Eds.), *Artificial intelligence and education: Vol. 1. Learning environments and tutoring systems.* Norwood, NJ: Ablex, 281–305.

Winn, B., 1987. Charts, graphs, and diagrams in educational materials. In D. M. Willows & H. A. Houghton (Eds.), *The psychology of illustration: Vol. 1*. New York: Springer-Verlag, 152-198.

Wogalter, M. S., DeJoy, D. M., Laughery, K. R., (Eds.), 2005. *Warnings and Risk Communication*. Philadelphia: Taylor & Francis Inc.

Wurman, R. S., 1997. *Information Architects.* New York: Watson-Guptill Publications Inc.

Wurman, R., Whitehouse, K., Sume, D. & Leifer, L., 2001. *Information anxiety 2.* Hayden, Quebec: Pearson Education.

Authors

Lou Tetlan was an Honorary Fellow at the University of Wisconsin School of Medicine and Public Health, serving in the Neuroradiology Lab on fMRI brain studies from 2009-September 2015. She received her Ph.D. in Curriculum and Instruction/ Art Education from the University of Wisconsin-Madison . Her research interest is in the neurobiology of learning. She is a national and international speaker with membership in the International Mind Brain and Education Society (IMBES), Design Research Society (DRS) and National Association of Professional Women (NAPW). She currently is researching, writing and educating groups on Cognitive-based Information Design (CID) on a full-time basis.

Douglas Marschalek is emeritus professor, Art Education/Art Department and Curriculum and Instruction, University of Wisconsin-Madison. His research and practice has involved application of design disciplines and education to the design of school environments, urban planning, object design, exhibit design, and information architecture. He believes that design has the potential to change and redesign education, such that learning occurs through design; and second, there is an untapped potential for design to shape school-based environments not previously met by interior designers and architects.