Learning From Visuals

How Visuals Can Help Students Learn

A White Paper
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Table of Contents

Introduction 1
How Do Learners Process Text and Visuals? 2
Learning is a Process of Building Mental Models 3
What is Cognitive Load? 3
How Visuals Help Build Mental Models and Reduce Cognitive Load 4
  Visuals engage learners in essential cognitive processes. 5
  Visuals display complex information efficiently. 6
  Examples of well-designed visuals from Wiley Visualizing 9
Six Methods For Using Wiley Visualizing in the Classroom 13
  1. Assign students to study visuals in addition to reading the text. 13
  2. Use visuals during class discussions or presentations. 14
  3. Use visuals during reviews. 15
  4. Use visuals for assignments and when assessing learning. 16
  5. Use visuals to situate learning in authentic contexts. 17
  6. Use visuals to encourage collaborative meaning making. 18
Conclusion 20
References 21
Introduction

Instructional materials, like textbooks, should be designed and used in ways that help students learn efficiently. For this to happen, instructional materials should reflect human cognitive architecture—how we learn. Research has provided a wealth of evidence that humans learn better from text and visuals together than from either medium alone. Thus, we may reasonably claim that a textbook designed to leverage both text and visuals can improve students’ learning.

As used in this paper, visuals are instructional components that visually display facts, concepts, processes, principles, or relationships among these. Unlike written or spoken verbal information, which are processed in linear, sequential form, visuals are processed in a more parallel, holistic fashion. Examples of visuals include diagrams, graphs, charts, maps, photographs, illustrations, schematics, animations, and videos.

This paper draws upon current research in the fields of cognitive science and educational psychology to describe how our minds process text and visuals. It illustrates how Wiley Visualizing has been designed to reflect human cognitive architecture, and how Wiley Visualizing can make more productive the effort that students put into learning. The paper concludes with suggestions for how instructors can effectively use the visuals in Wiley Visualizing in the classroom.

Although the principles of human learning discussed in this paper apply to all sources of instruction, this article focuses solely on textbooks. It makes no assumption that the theories or principles described in the paper are original. The research cited is based primarily on two very influential theories: Richard Mayer’s Cognitive Theory of Multimedia Learning and John Sweller’s Cognitive Load Theory. Allan Paivio’s Dual-Coding Theory strongly influenced these two theories. The final two sections of the article, however, put forward original ideas about how the research has been used within Wiley Visualizing, and how Wiley Visualizing can support classroom instruction.

There is a widely held belief that a finite number of learning styles exist, that we each have a learning style, and that when instruction matches that style we are more likely to learn. However, research has found little, if any, evidence to support the belief that designing instruction to accommodate learning styles improves learning (Clark & Feldon, 2005). Learning can be affected when instruction is designed to accommodate certain individual differences such as motiva-
tion, prior knowledge, and spatial aptitude. However, the strongest evidence supports the belief that learning is facilitated most effectively when instruction is designed to reflect general properties of human cognitive architecture that apply to all learners. This is the evidence on which this paper is based.

How Do Learners Process Text and Visuals?

Current research on human learning supports a model of cognitive architecture similar to Figure 1, below (adapted from Mayer, 2001 and Paivio, 1986).

Figure 1: Human Cognitive Architecture

According to this model, information from instructional materials enters working memory through two separate channels: one channel for visual information and the second for verbal or textual information. In working memory, we begin to make sense of words and visuals, and build verbal and visual models of the information. These models reflect our understanding of the information as presented through textual or visual media.

Visual and verbal models can be integrated when the text and visuals provide corresponding representations of the information, allowing a learner to form a more comprehensive mental model. However, the strongest mental models are formed when a learner is able to link new information to prior knowledge. Linking new information to prior knowledge increases the likelihood that the new information will be retained in long-term memory. Learning occurs when an integrated mental model is formed and stored in long-term memory (Mayer, 2001).
Learning Is a Process of Building Mental Models

When information enters into working memory, we begin to make sense of it by building mental models, sometimes called schemas (Sweller, 1999). Mental models reflect our individual understanding of the information presented to us, and are composed of the words or visual elements that we pay attention to and organize into a logical whole (Mayer, 2005a). We can build more comprehensive mental models when we integrate visual and verbal models of information. Meaningful and lasting learning occurs when these integrated mental models are linked to prior knowledge and retained in long-term memory (Mayer, 2005a).

Consider an example of building a mental model. If a student reads a passage of written text about the order of the planets in the solar system, she begins to understand the information based on the words alone. She builds a verbal model of the information. If that student studies an illustration of the order of the planets, she begins to understand the information based on the visual representation. She builds a visual model. However, if the student reads the information and studies an illustration based on that text, she builds both a verbal and a visual model. The text enhances visual understanding and the illustration facilitates verbal understanding.

What Is Cognitive Load?

There are limits to our working memory’s capacity to process information. Working memory can process only a small amount of information at one time, and that information is retained in working memory for only a short while. Therefore, if instructional materials require learners to process more information than working memory can handle, the learning process can be impaired. A learner will not build a complete or accurate mental model. This is especially true with beginning learners, when the content is new to the learner, or when the content is complex by nature. In these cases, a learner does not automatically know what information to pay attention to or how to organize it. And our cognitive architecture does not simply record every word we read and every visual we see.
The effort we must put forth to make sense of instructional information is called cognitive load (Clark & Lyons, 2004; Clark, Nguyen & Sweller, 2006). Some cognitive load comes from the complexity of the instructional content. This type of load is referred to as intrinsic cognitive load. Some cognitive load is created by the design of learning materials, especially when the design does not reflect our knowledge about the human cognitive architecture or facilitate information processing in working memory. This type of load is referred to as extraneous cognitive load, and can be reduced by following good instructional design guidelines.

A positive type of cognitive load, called germane cognitive load, is the productive effort that learners put forth to build mental models. When a learner is engaged in a learning task, such as studying a well-designed visual that contributes to a mental model, they are experiencing germane cognitive load.

Two important goals in creating learning materials, like textbooks, are to

1. Help students construct mental models, and
2. Reduce extraneous cognitive load.

Research has shown that these two goals are best achieved through the use of text and visuals together.

### How Visuals Help Build Mental Models and Reduce Cognitive Load

Research offers practical principles for effectively designing and using visuals and text (Clark & Lyons, 2004; Clark, Nguyen & Sweller, 2006; and Mayer, 2005). This section describes how well-designed visuals, in conjunction with text, can help students build mental models while reducing unnecessary extraneous cognitive load. First, well-designed visuals and text prompt learners to engage in essential cognitive processes. Second, well-designed visuals often display complex information in a more efficient manner than text alone. Sample visuals are provided that exemplify how Wiley Visualizing has designed visuals to achieve these two goals.
Visuals engage learners in essential cognitive processes.

When visuals and text are combined following proven design guidelines, they direct learners’ attention to important information, organize the information into a logical structure, and integrate visual information with verbal information. Good design of text and visuals helps learners to complete these processes in working memory, greatly strengthening their understanding (Mayer, 2005). These cognitive processes are those that are essential for building accurate and comprehensive mental models. There are different categories of visuals, based on the way they direct attention, organize information, and integrate information. Table 1, below, (adapted from Clark & Lyons, 2004) provides a common classification scheme.

Table 1: Common Categories of Visuals

<table>
<thead>
<tr>
<th>Category of Visual</th>
<th>Primary Use</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decorative</td>
<td>Provide aesthetic, non-instructional appeal</td>
<td>Decorative patterns on book covers</td>
</tr>
<tr>
<td>Representational</td>
<td>Realistically depict an object or objects</td>
<td>Photograph or line drawing of automobile engine components</td>
</tr>
<tr>
<td>Mnemonic</td>
<td>Create memory cues</td>
<td>Objects, whose pronunciation in English sounds similar to a Spanish vocabulary word</td>
</tr>
<tr>
<td>Organizational</td>
<td>Show qualitative relationships</td>
<td>A map depicting the relationship of legislative, executive, and judiciary powers</td>
</tr>
<tr>
<td>Relational</td>
<td>Show quantitative relationships</td>
<td>Statistical charts or graphs</td>
</tr>
<tr>
<td>Transformational</td>
<td>Depict spatial or temporal changes</td>
<td>Flow charts, procedural charts, systems diagrams that show sequence of events</td>
</tr>
<tr>
<td>Interpretive</td>
<td>Illustrate cause/effect relationships or abstract principles</td>
<td>Schematics, atomic diagrams</td>
</tr>
</tbody>
</table>
Visuals display complex information efficiently.

While also engaging learners in essential cognitive processes, visuals and text should be designed to function together to reduce cognitive load. Well-designed visuals can often display complex information in a more efficient manner than text alone. A visual can display multiple pieces of information as a single unit, whereas several sentences or more would be required to communicate the same information in text. This efficiency can actually increase a learner’s effective working memory capacity (Sweller, 2005). Several effects have been identified that describe how visuals and text should be designed to best facilitate learning.

The split-attention effect describes the phenomenon of combining text with visuals in ways that increases extraneous cognitive load. “Instructional split-attention occurs when learners are required to split their attention between, and mentally integrate, several sources of physically or temporally disparate information, where each source of information is essential for understanding the material” (Ayres & Sweller, 2005). Split attention is a common problem in textbooks where visuals are physically separated from the text that describes them. Cognitive load caused by split attention can be reduced by physically integrating text with visuals, allowing working memory to process them together.

Figures 2 and 3, below, illustrate the differences between visuals that create split attention and visuals that eliminates it. Figure 2 demonstrates one common instance of split attention and Figure 3 demonstrates how the split attention can be eliminated by integrating visual and textual elements.
Figure 2: Sample Visual that Creates Split Attention

Visual elements in the upper section are physically separated from the textual explanations in the lower section in Figure 2. This creates split attention and increases cognitive load.
Figure 3: Sample Visual that Eliminates Split Attention

Textual elements have been physically integrated with the visual explanations in Figure 3. This eliminates split attention and reduces cognitive load.
Examples of well-designed visuals from Wiley Visualizing

Directing attention means that a learner pays attention to and recognizes important features, characteristics, steps, or relationships. In text, directing attention is often done by bolding or italicizing words. A visual can direct a learner’s attention by using connecting lines, labels, highlighting, or color-coding. Notice how Figure 4 below labels sections of the brain, focusing a learner’s attention to the relevant areas.

At the same time, Figure 4 has been designed to minimize split attention. The connecting lines physically link the visual with the text labels. Doing so allows our brain to see the text and visual as one unit. A less-effective design might have labeled each of the sections with a letter (A, B, C, etc.) and placed the text descriptions in a caption below the visual. In such an example, learners would have to split their attention between the physically separated visual and text descriptions.

*Figure 4: Example of Directing Attention*
A mental model is an organized structure of information. The information could be organized logically, spatially, or procedurally (such as flowcharts or systems diagrams). Using visuals to illustrate organization makes learning more efficient. Visually representing the organization reduces the cognitive load that a learner must expend to organize it. This is especially true when the information is spatial in nature, such as models or geographical features. However, abstract information can also be represented visually, as in the case of tables, graphs, and matrices.

The organization of information is readily apparent in the examples below. Figure 5 is a more traditional matrix, with four separate categories of information organized into columns and their relationships are immediately seen. The reduction of cognitive load is especially apparent in matrices and tables. A reader does not need to split her attention between visuals and text; both are neatly aligned in rows and columns. All extraneous or distracting information is removed.

**Figure 5:** Example of Organizing Information in a Matrix

Visually displaying processes is another effective way to help learners organize complex information. Figure 6 depicts the hydrologic cycle and effectively organizes the several components of the system in a logical structure. The information displayed could have been found on several pages if it were exclusively in text.

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**Polymerization and the common silicate minerals**

This chart summarizes the ways in which silicate ions can polymerize to form minerals. Typical examples of each type are shown in the photographs. There are many other silicate minerals in each category, but all of the principal categories that occur in nature are illustrated here.

<table>
<thead>
<tr>
<th>Silicate Structure</th>
<th>Mineral/Formula</th>
<th>Cleavage</th>
<th>Example of a specimen</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single tetrahedron</td>
<td>Olfite Mg₂SiO₄</td>
<td>None</td>
<td>![Image]</td>
</tr>
<tr>
<td>Hexagonal ring</td>
<td>Beryl (Gem form is emerald) Be₃Al₂Si₆O₁₈</td>
<td>One plane</td>
<td>![Image]</td>
</tr>
</tbody>
</table>
Figure 6: Example of Organizing Process Information

The benefit of the visual display is the ease with which a learner can recognize relationships among the different components of the system. The process arrows are very beneficial in this way. Learners immediately see how components are related to each other, facilitating interpretation. Figure 6 is also a fine example of the integration of text and visuals to reduce split attention. The brief text descriptions have been physically integrated into the visual so a reader does not have to look below the visual for an explanation. Even having a description of the system next to the visual would have split learners' attention.

One final example of visually organized information, Figure 7, illustrates how text and visuals can be integrated to organize information and reduce split attention. In this case, several related events have been organized chronologically. Text descriptions and visual representations have been physically integrated.
Some of the information in a visual such as this one may be familiar to a learner. For instance, a learner may know about Charles Darwin and the Origin of the Species, two of the items on the timeline in Figure 7. By integrating related events, dates, and figures on the same visual, whatever information is new to the learner is linked to that prior knowledge. Linking new information to prior knowledge makes it more likely that an integrated mental model will be retained in long-term memory.
Six Methods For Using Wiley Visualizing in the Classroom

To this point, I have discussed our cognitive architecture and how learning occurs. I have also discussed several ways in which visuals—the combination of text and images—can reduce cognitive load and support learning through building mental models. Beginning students especially benefit when information is presented verbally and visually. However, integrating visual and verbal mental models is a complex meta-cognitive skill, and not all students have developed it.

Instructors have an important role in using well-designed visuals in the classroom to ensure that learners derive as much benefit from them as possible. Students should be guided in making the connections between text and visuals, and then linking these to prior knowledge. Here are six recommendations for using the visuals in Wiley Visualizing in classroom instruction to help students make connections between visual and verbal mental models.

1. **Assign students to study visuals in addition to reading the text.**

Instead of assigning only one medium of presentation, make sure your students know that the visuals are just as important as the text. The photographs in Figure 8 could be studied as students read about consumption of natural resources in different parts of the world. The photos provide a concrete visual representation of the textual information and help students make sense of abstract concepts.

*Figure 8: Assign Students to Study Visuals in Addition to the Text*
2. Use visuals during class discussions or presentations.

Point out important information as the students look at the visuals. With Figure 9, an instructor can discuss important features of radioactive decay, while using the visual to direct students’ attention to key visual elements, helping them begin to organize the information and develop an integrated mental model.

**Figure 9: Discuss Visuals in Class to Direct Attention to Important Information**

With instructor guidance, students can integrate separate visual and verbal mental models that they may have developed. The verbal explanation of important information combines with the visual representation and can lead to an integrated mental model.
3. Use visuals during reviews.

Students can review key vocabulary, concepts, principles, processes, and relationships displayed visually. Figure 10, showing the sensory areas of the brain, highlights key physical features, and a student can quickly review and recall the vocabulary, and physical relationships.

Figure 10: Use Visuals to Review Important Information

Integrated mental models are built when new information in working memory is linked to prior knowledge. If a student were to review Figure 10 before studying a new chapter in the textbook, the visual could help stimulate prior knowledge to which the information in the new chapter could be linked.
4. Use visuals for assignments and when assessing learning.

When students develop integrated mental models, their recall can be improved. Visuals can be used for comprehension activities or assessments. For example, students could be asked to identify examples of concepts portrayed in visuals. Figure 11, of horizontal rock strata in the Badlands, could be used to assess students’ ability to identify different geologic formations.

*Figure 11: Use Visuals as the Basis For Assignments*

When learners develop visual models of information they can recreate models, label components of images, explain visually displayed processes, identify real-world examples of visually displayed information, and transfer concepts to novel problems. These types of activities can be excellent demonstrations of learning.

Higher-level thinking activities can also be based on visuals. They can be very useful for drawing inferences, for predicting, and for problem solving. Develop activities that require critical thinking, deductive and inferential thinking, and prediction based on visuals. For instance, Figure 12 includes a question that asks students to make predictions based on features in the photograph. Because this particular visual appears within a chapter summary it allows students to reflect on the concepts from the previous chapter. They are required, cognitively, to apply a mental model they built while reading and studying the chapter to a new problem situation.
5. Use visuals to situate learning in authentic contexts.

Learning is made more meaningful when a learner can apply facts, concepts, and principles to realistic situations or examples. Visuals can provide that realistic context. For instance, Figure 12, above, displays features which may already be familiar to many students. A discussion of the concepts related to the image becomes more meaningful because the student is familiar with similar formations.

The two photographs shown in Figure 8 provide an authentic context for the text’s discussion of consumption of natural resources in different areas of the world. The visual provides a realistic and easily interpretable representation that supports a student’s understanding of the text.

Likewise, Figure 13, below, shows a photograph of the Grand Canyon, an image familiar to many students. In this usage, however, the familiar context illustrates key information about stratification of rock, linking new concepts to prior knowledge in an authentic and familiar context.
6. Use visuals to encourage collaborative meaning making.

Visuals can be used as the centerpiece of collaborative activities, requiring students to study, make sense of, discuss, hypothesize, and make decisions regarding the content of the visual. Figure 14 provides a diagram of the relationships between several concepts related to economics and the environment. Students can work together to interpret and describe the diagram. A more complex activity might involve scenarios or projects that require groups of students to use the diagram to solve problems, conduct research related to the topic, or work through a case study activity.
Collaboration can help clarify students’ understanding of the content, facilitating the building of integrated mental models. Students can collaborate and use techniques to build verbal mental models from visuals. Collaborative groups often are required to practice interactive processes such as giving explanations, asking questions, clarification of ideas, and argumentation. These interactive, face-to-face activities provide the verbal information needed to build a verbal mental model. Learners also benefit from collaboration in many instances such as decision making or problem solving.
Conclusion

Effective use of both text and visuals can improve the quality of learning from textbooks by supporting the processes by which all people learn. The use of text and visuals helps build mental models by directing attention to important information, organizing information, and integrating visual and verbal models into comprehensive mental models. The two media can reduce unnecessary cognitive load on learners by eliminating split attention and increasing learner engagement with the content (germane cognitive load). As demonstrated by the examples provided, Wiley Visualizing draws upon empirical research on the use of visuals and makes effective use of them to support learning. Recommendations for how instructors can effectively use the visuals in Wiley Visualizing in their classrooms have also been provided.
References


