LEARNING FROM VISUALS
How Well-Designed and Well-Used Visuals Can Help Students Learn
An Academic Review

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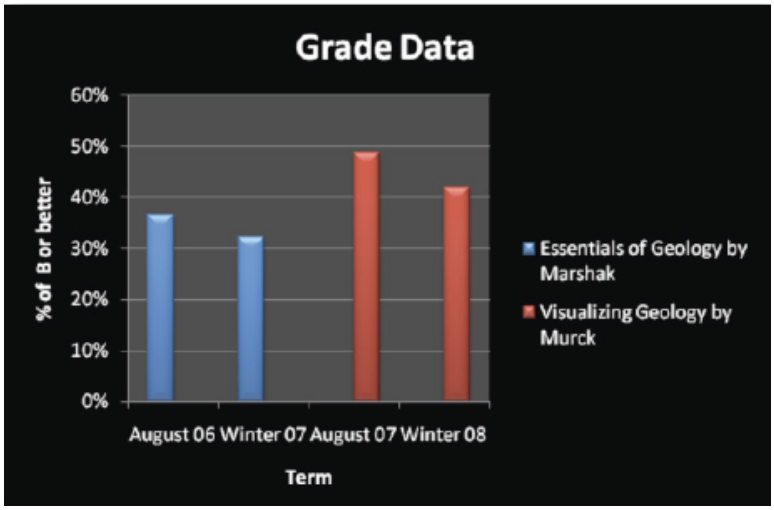
Wiley Visualizing: An Approach That Works

Instructional messages, like those in textbooks should be designed and used in ways that help students learn, not just to communicate bodies of information. For learning to take place, instructional messages must reflect human cognitive architecture – the way our brains make sense of information. Research has provided a wealth of evidence that we learn better from text and visuals together than from either medium alone. Wiley Visualizing is a series of books built on the premise that a textbook designed to leverage both text and visuals in ways that reflect students' cognitive architecture can improve students' learning.

Since Wiley Visualizing was launched, student performance has been tracked for classes using books in the Series to measure the effectiveness of the visual approach the Series employs. At The Ohio State University, Mansfield, Professor Ozeas S. Costa found that on average, the number of students getting a B or better on his final exam increased by nearly 32% while using *Visualizing Geology* by Murck et al compared to the traditional text that his students had previously used. (Figure 1)

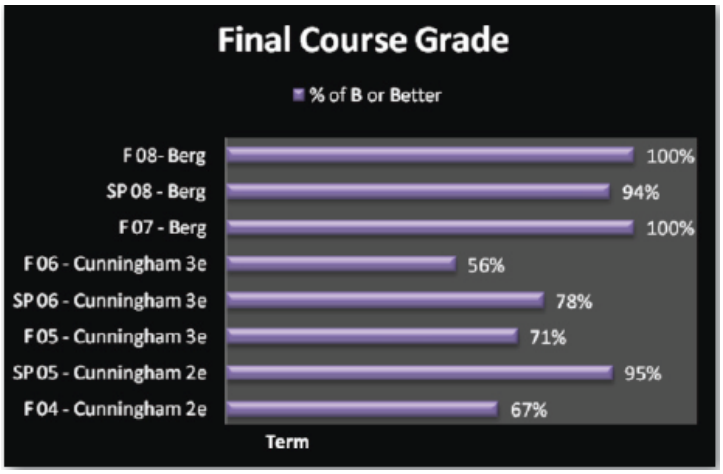
Figure 1: Comparison of Grade Data - *Visualizing Geology*



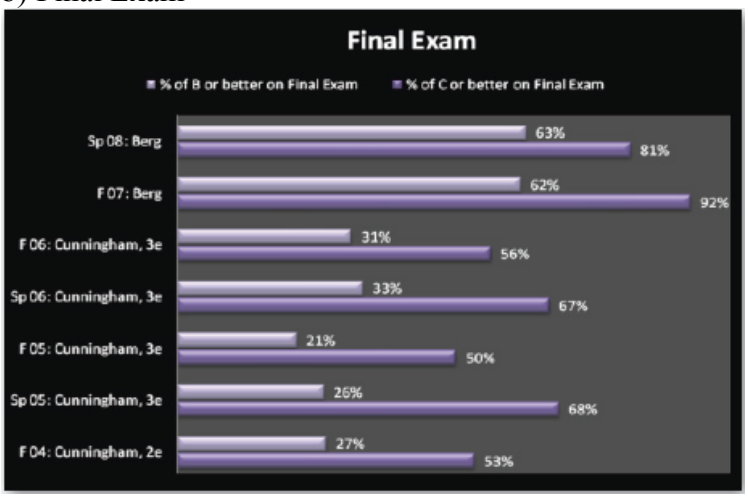
Similar levels of improvement have been documented with diverse students and schools. At Gateway Community College, Professor Cheryl Berg saw the percentage of B or better final course grades go up from 56% in the Fall of 2006 when students used a traditional text, to close to 100% when students started using *Visualizing Environmental Science* by Berg. (Figure 2).

Figure 2a, b : Comparison of Grade Data- *Visualizing Environmental Science*

a) Final Grade



b) Final Exam



The paper puts forward original ideas about how research has been used within Wiley Visualizing and how these texts can support classroom instruction that leads to the results that have been documented. As used here, visuals include diagrams, graphs, charts, maps, photographs, concept maps, animations, and videos. Effective instructional visuals, as will be made clear, integrate both graphical elements as well as textual elements.

Although the principles of human learning apply to all sources of instruction, this article focuses solely on textbooks. It makes no assumption that the theories or principles of human learning are original. The approaches described are 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.

There is a widely held belief that a finite number of learning styles exist (e.g., auditory, visual, kinesthetic, etc.), that we each have a preferred or best learning style, and that when instruction matches that style we are more likely to learn. People believe in learning styles out of experience, but empirical evidence has not been able to show that

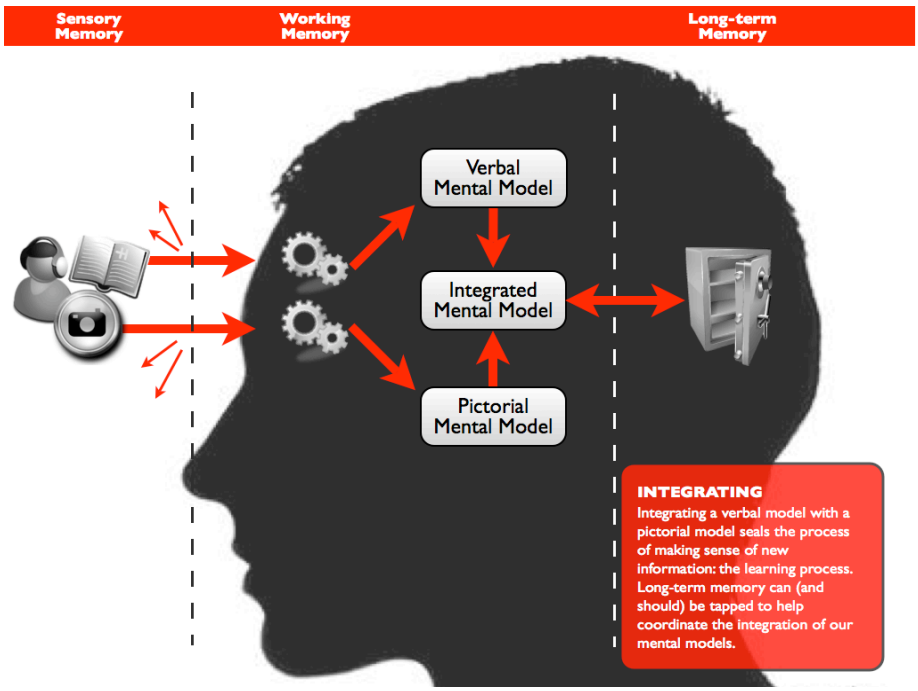
these learning styles influence learning outcomes. Since theory has given us many ways to support learning that works for all types of learners, this review will focus on these general principles

Knowledge Structures in Mental Models

The effort we must put forth to make sense of new information is called cognitive load (Clark, Nguyen & Sweller, 2006). Some cognitive load comes from the complexity of the instructional content. This is called intrinsic cognitive load. Some load is created by the design of learning materials, especially when the design does not reflect how our cognitive architecture processes information. This type of cognitive load is referred to as extraneous cognitive load. A positive type of cognitive load, called germane cognitive load, is the productive effort that students put forth to build mental models. When a student 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.

Instructional messages that communicate corresponding verbal and pictorial messages will lead students to construct verbal and pictorial models that can map to each other (Figure 3). That is, when information in verbal messages relates to the information in pictorial messages, an integrated mental model is formed.

Figure 3: Integrating Mental Models with Prior Knowledge



The strongest mental models are formed when a student 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, 2009).

The process of organizing information to build mental models is a process of connecting pieces of information into knowledge structures. Mayer (2009, p.69) outlines five common knowledge structures. Table 1 is based on his summary.

Since the learning process is a process of constructing knowledge structures, our instructional messages should display the structures of the information we are teaching and assist students in recognizing those structures. Effective visuals will also display the structure of the instructional message and will guide students to construct a corresponding mental model for themselves.

Table 1: Five Common Knowledge Structures

Structure	Description	Examples
Process	Explaining sequences, cause/effect relationships, or principles	Flowcharts, Photo Sequences, Stepwise Illustrated Directions
Comparison	Comparing or contrasting multiple elements along multiple dimensions	Tables, Matrices, Graphs
Generalization	Describing a main concept and sub- or supporting-concepts	Hierarchies, Concept Maps
Enumeration	Presenting lists of concepts, items, or elements	Lists, Charts
Classification	Breaking down a topic into its component parts	Hierarchies

Effectively Designed Visuals Best Help Students Learn

If visuals are to be effective teaching and learning tools, it is absolutely critical that they are designed to reflect our cognitive architecture (Clark & Mayer, 2008; Clark, Nguyen & Sweller, 2006; Mayer, 2009). Visuals must be carefully designed and used to help students select relevant information, organize it, and integrate it – all while not adding extraneous cognitive load. But what do visuals that perform these functions look like? How can we recognize effective visuals?

One way to think about designing effective visuals is to categorize visuals into ascending levels of pedagogical usefulness- Decorative, Representational, Organizational and Explanative. (Mayer, 2009). Table 2 describes and demonstrates these levels.

Table 2: Categorization of Visuals

Category of Visual	Instructional Potential	Examples
Decorative Visuals used for aesthetic appeal, entertainment, or to stimulate interest	None	Photograph of surgeons performing heart surgery at the beginning of a lesson on the human heart Photograph of the Hubble telescope floating in orbit above the earth Newspaper clipping showing photographs of three teenagers with the headline "Local Teens Killed in Drunk Driving Crash"
Representational Visuals that portray a single object or piece of information in isolation from related objects or pieces of information	Minimal to None	Drawing of the human heart, labeled "The Human Heart" Hubble telescope photograph of a distant galaxy with the galaxy's name and description Photograph of a young person drinking alcohol with the caption "7.2 million young people under the age of 17 tried alcohol at least once last year"

Organizational Visuals that display relations, structures or organization among multiple objects or pieces of information	High	Drawing of the human heart, labeled "The Human Heart," and with the major anatomical features labeled or outlined Hubble telescope photographs of different categories of galaxies with brief text explanations of the identifying features of each category Line graph titled "Alcohol Use Among Teens" showing data from 1950-present
Explanative Visuals that explain how systems, processes, or cause/effect sequences work	High	Drawing of the human heart with directional arrows indicating blood flow and numbered explanations of how the heart pumps blood through the heart Sequence of illustrations with accompanying brief explanations of how galaxies form, starting with the Big Bang and ending with a photo of a galaxy taken by the Hubble telescope A graphic organizer, preceding a chapter on alcohol abuse among teens, that visually summarizes various causes and consequences of teen alcohol abuse, adapted from statistical data

Organizational and Explanative visuals are the most valuable types for instruction and learning because they help learners more completely build mental models. These types of visuals help learners select relevant information, organize that information into a recognizable structure, and integrate the verbal and pictorial models that students generate.

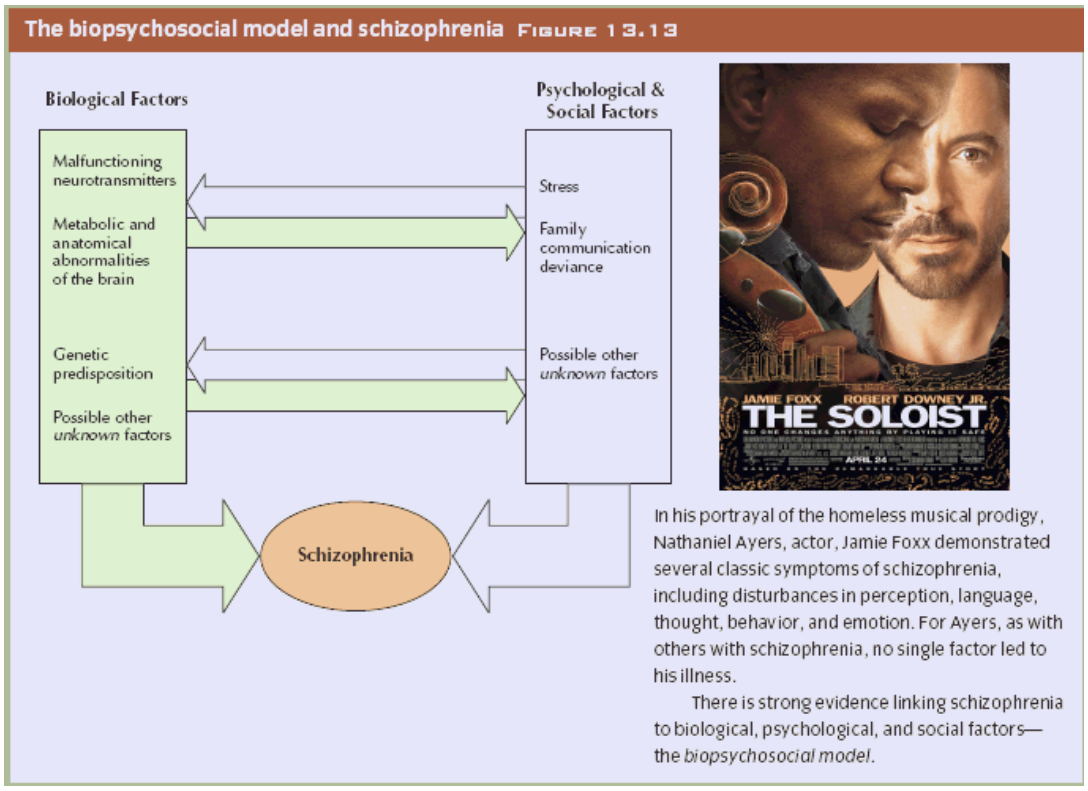
Note that an integral feature of these visuals is not just the photograph or illustration, but the integration of text explanations, interpretations, or guidance. Visuals with integrated

text explanations have repeatedly been shown in research to be more effective at teaching than either visuals or text alone (Fletcher & Tobias, 2005).

Decorative visuals engage learners in none of these three essential cognitive processes; they are purely aesthetic in nature. Representational visuals may help learners select relevant information, but because they display a single object or concept in isolation they cannot give that information a structure that will help learners organize it. More experienced learners may be capable of structuring the information in a representational visual without that help using their prior knowledge, but novices in the subject matter will not be able to.

On the other hand, decorative and representational visuals can be combined with organizational or explanative visuals, thus increasing their instructional potential. For example, Figure 4 is an explanative visual from *Visualizing Psychology*, 2nd edition, illustrating the multiple factors scientists have discovered that contribute to schizophrenia. The representational photo from the movie "The Soloist" adds a concrete example that can further the understanding of the causes of schizophrenia for students familiar with the movie.

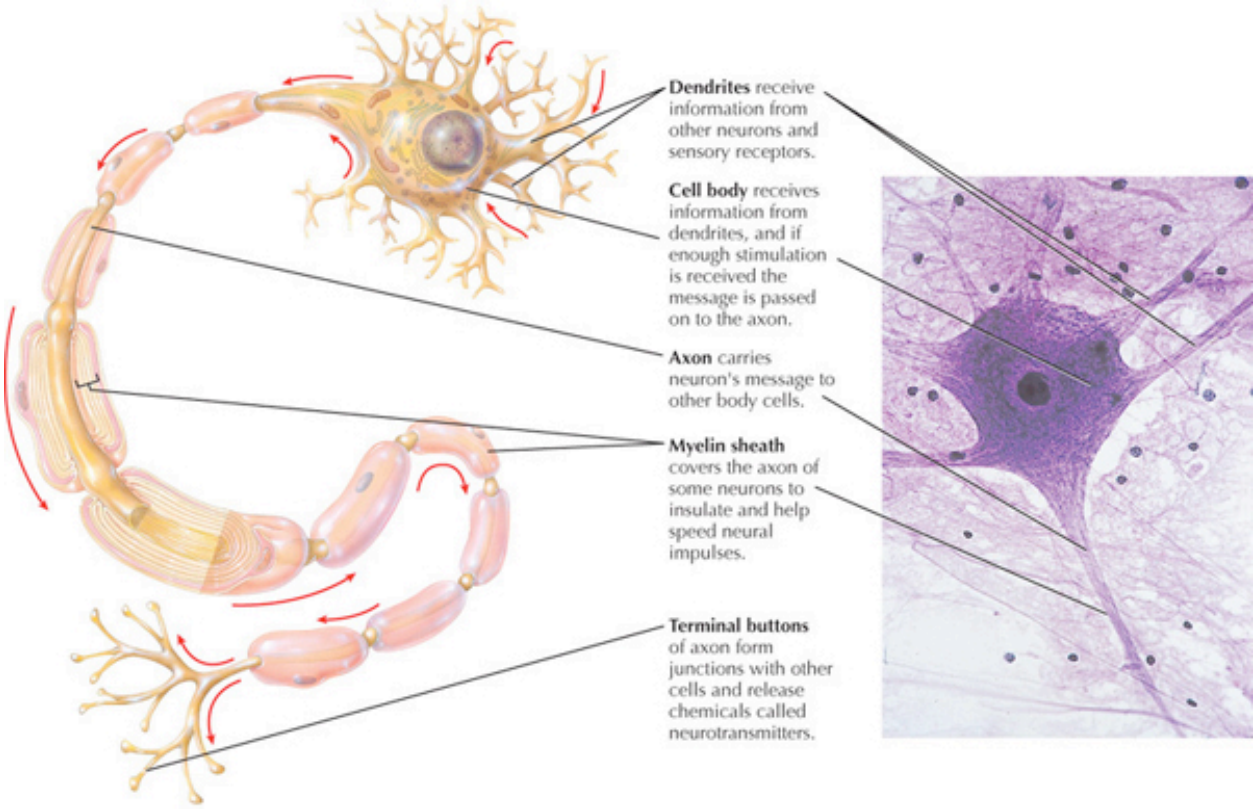
Figure 4: Effective Combination of a Representational Visual with an Explanative Visual



Examples of Well-designed Visuals from Wiley Visualizing

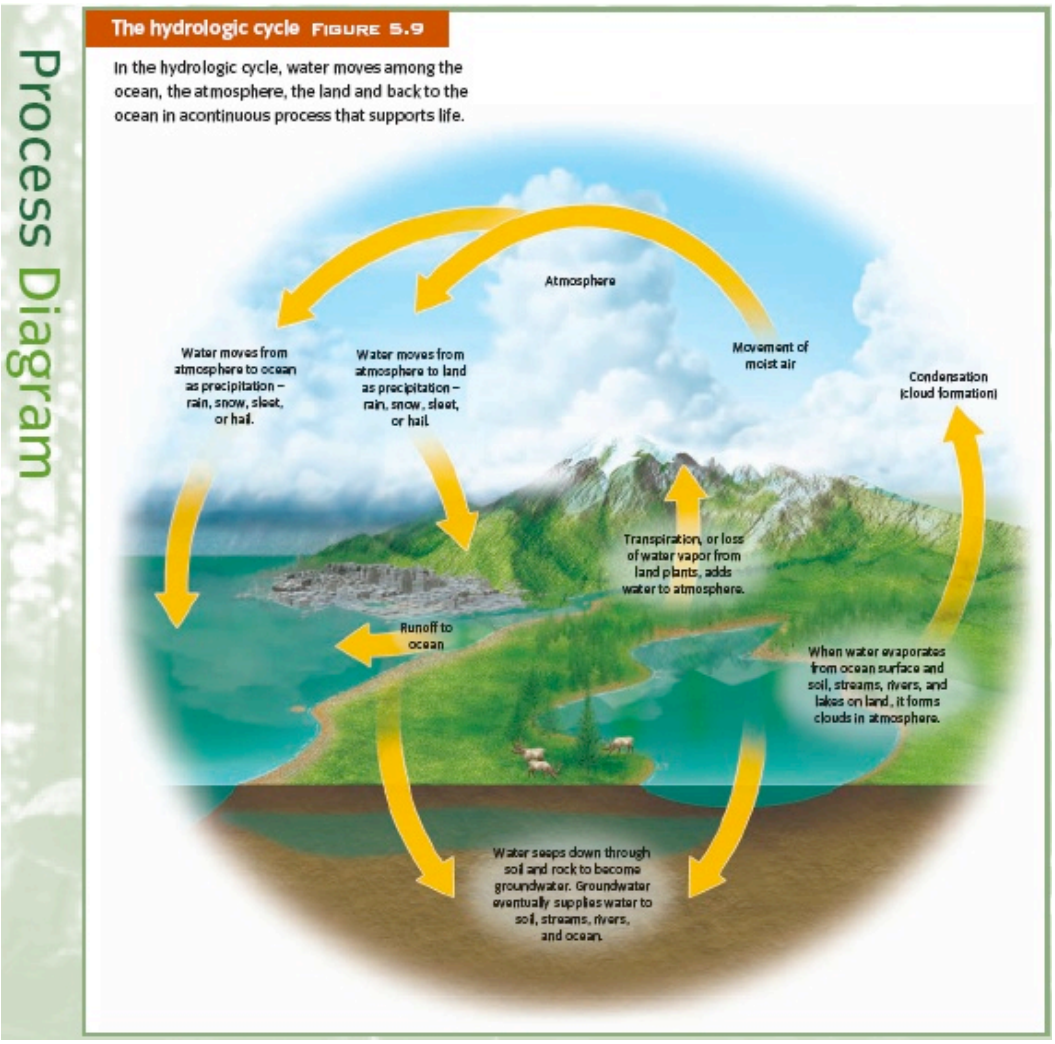
Figures 5-11 are examples of visuals from Wiley Visualizing texts that have been designed to reflect human cognitive architecture and can be effective for teaching and learning. These examples are all either Organizational or Explanative visuals.

Figure 5: Organizational Visual (from *Visualizing Psychology*, 2nd edition)
Anatomical features of neurons



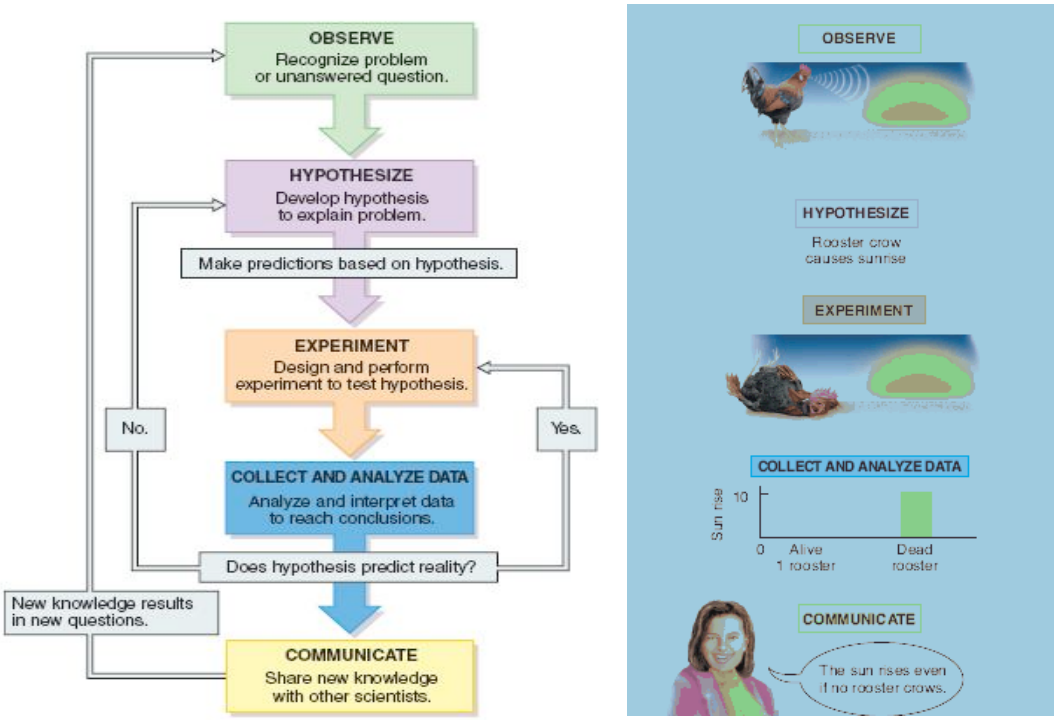
The integration of text reduces cognitive load and help build verbal and pictorial models in working memory.

Figure 6: Organizational Visual (from *Visualizing Environmental Science*, 1st edition)
The hydrologic cycle



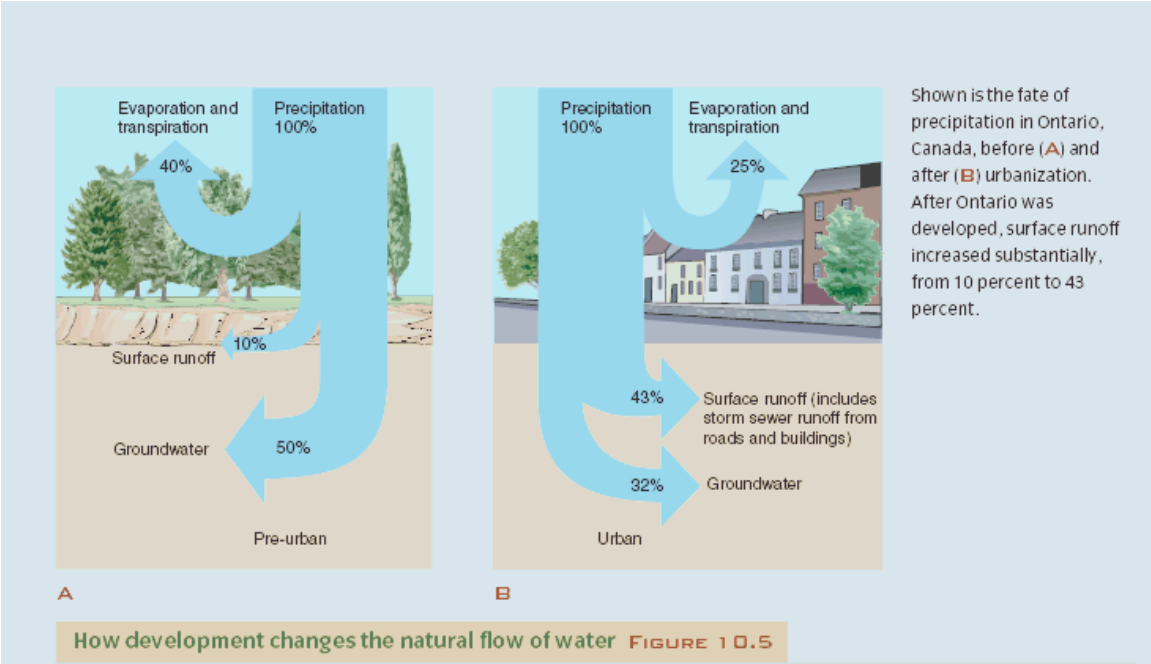
The visual layout of system with parts labeled communicates the information efficiently but also gives it a structure that can be efficiently integrated into a mental model. Processes are one structure into which working memory attempts to organize information.

Figure 7: Explanative Visual (from *Visualizing Human Biology*, 2nd edition)
Steps of the scientific method as a system



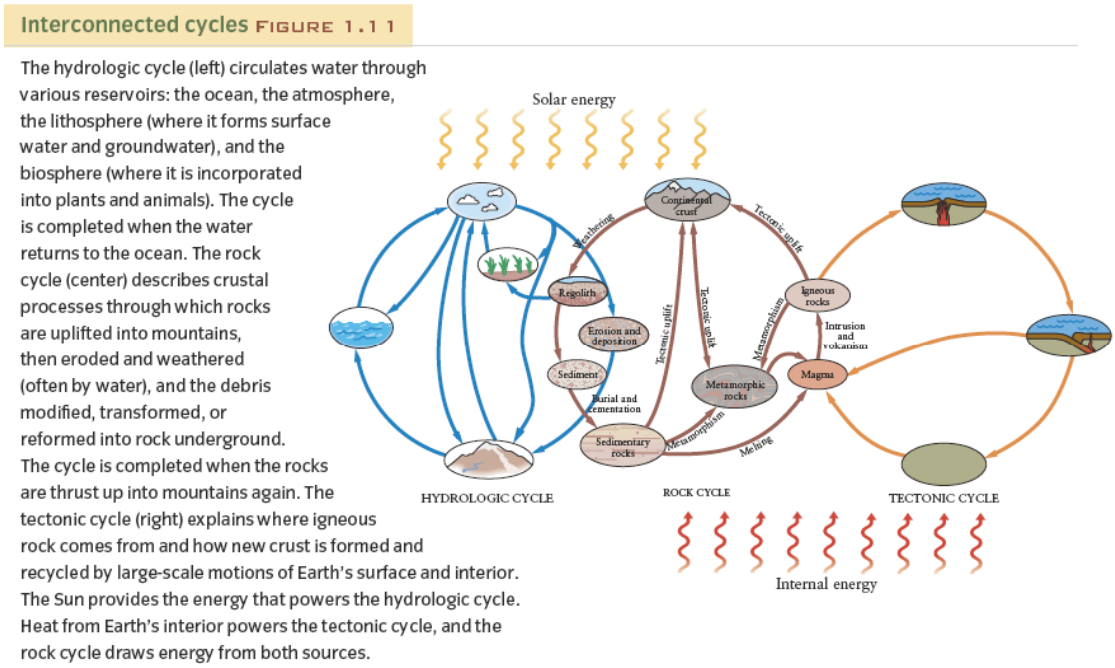
Clear labeling with a brief explanation, aiding a learner in selecting the information. Displaying the scientific method as a system provides a student with a knowledge structure to help organize the new information.

Figure 8: Explanative Visual (from *Visualizing Environmental Science*, 2nd edition)
Fate of precipitation in an area prior to and after urbanization.



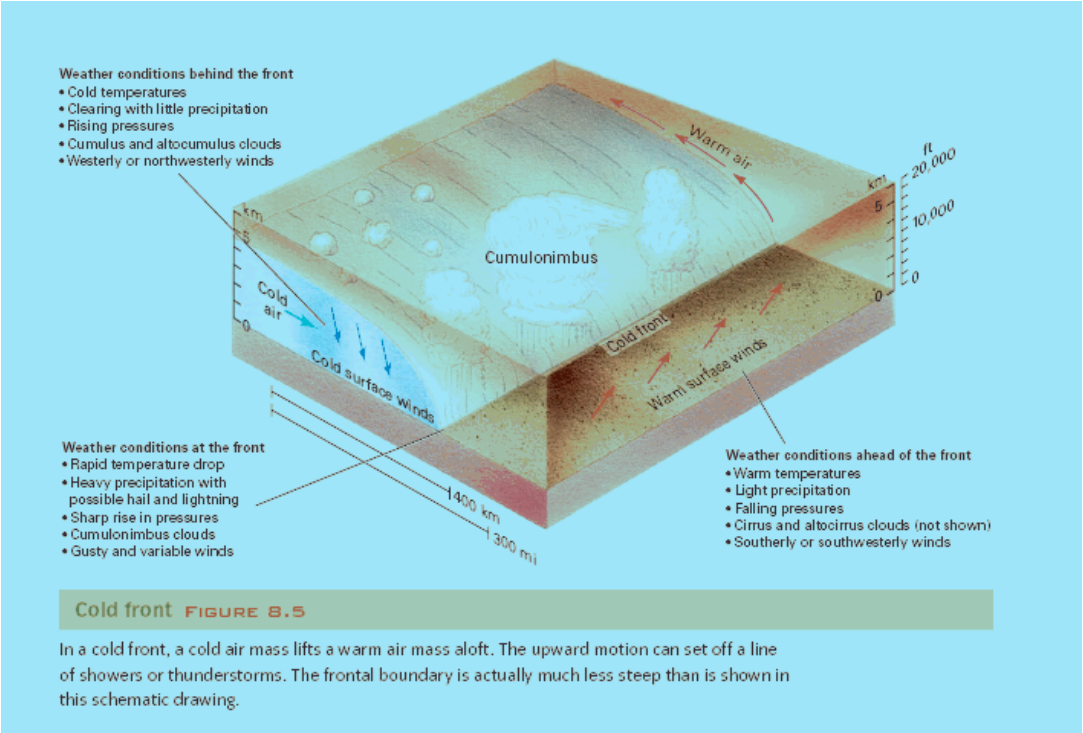
The features of the visual are clearly labeled and the overlay of the arrows of varying widths on top of the simple, non-distracting illustration helps guide a student to efficiently make sense of the comparative data.

Figure 9: Explanative Visual (from *Visualizing Geology* 2nd edition)
Displays the interconnected Earth cycles.



This visual is shown at the beginning of the book and acts as a preview of the structure of the information as it is explained in the subsequent chapters. As such, it prepares students to select and organize the information that will follow in the book, enabling working memory to work more efficiently when processing the information.

Figure 10: Explanative Visual (from *Visualizing Weather and Climate*)
Weather conditions associated with cold fronts

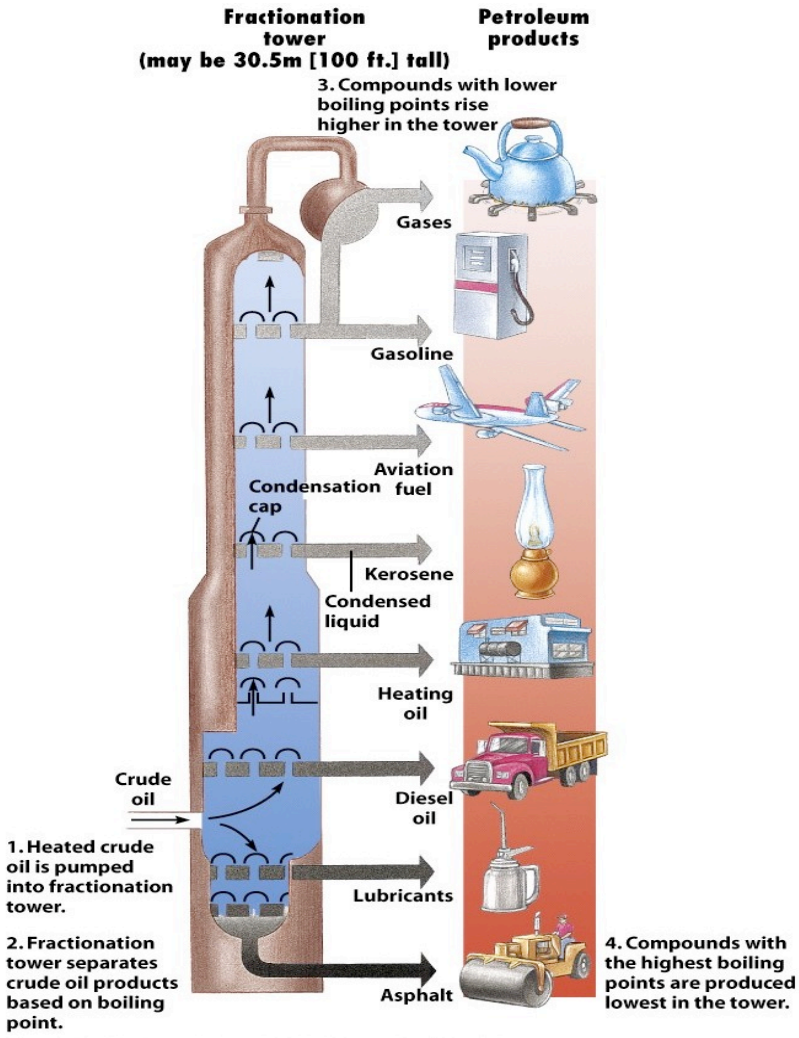


Cold front FIGURE 8.5

In a cold front, a cold air mass lifts a warm air mass aloft. The upward motion can set off a line of showers or thunderstorms. The frontal boundary is actually much less steep than is shown in this schematic drawing.

The text integrated with the illustration reduces cognitive load and helps a learner integrate verbal and pictorial models.

Figure 11: Explanative Visual (from *Visualizing Environmental Science*, 2nd edition)
Various products made from crude oil



System processes and flow are illustrated, helping to organize the information. Text explanations, more than just labels, help integrate verbal and pictorial models.

Six Methods for Using Wiley Visualizing in the Classroom

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. Instructors can help students select relevant information, organize it, and then integrate it. This, from a high-level perspective, summarizes much of the task of teaching: helping students meaningfully understand a subject, that is, helping them build mental models.

Below are six recommendations for using the visuals in Wiley Visualizing in classroom instruction to help students build mental models. Since the visuals in Wiley Visualizing are explicitly developed with these cognitive processes in mind, they prepare an instructor that much better to guide their students towards learning.

Six Methods for Using Wiley Visualizing in the Classroom
Use visuals during class discussions and presentations. Use visuals during review sessions. Use visuals for assignments and when assessing learning. Use visuals to situate learning in authentic contexts. Use visuals to encourage collaborative meaning making. Assign students to study visuals in addition to reading the text.

1. Use visuals during class discussions and presentations.

Many, if not most of us, include some sort of visual in our classroom presentations. If you teach online, you may make even more of an attempt to make your materials visual. Remember, however, that effective use of visuals mean much more than just including them in our presentation materials.

Presentations and discussions are prime times to help students select relevant information, organize it and integrate it. Use visuals to organize and explain key points, not just to represent concepts. Use organizational visuals, for example, as advance organizers to help students see the organization of a lecture or the connection between multiple lectures or topics. This is a better use of visuals than using a photograph or illustration of a single concept or topic at the outset of a lecture or presentation.

If you are using a visual during a live presentation, try not to include a large amount of text with the visual; your verbal explanation will provide the verbal information that the students will use to build a verbal model. Therefore, keep your explanations succinct so as to not overwhelm working memory with too much information.

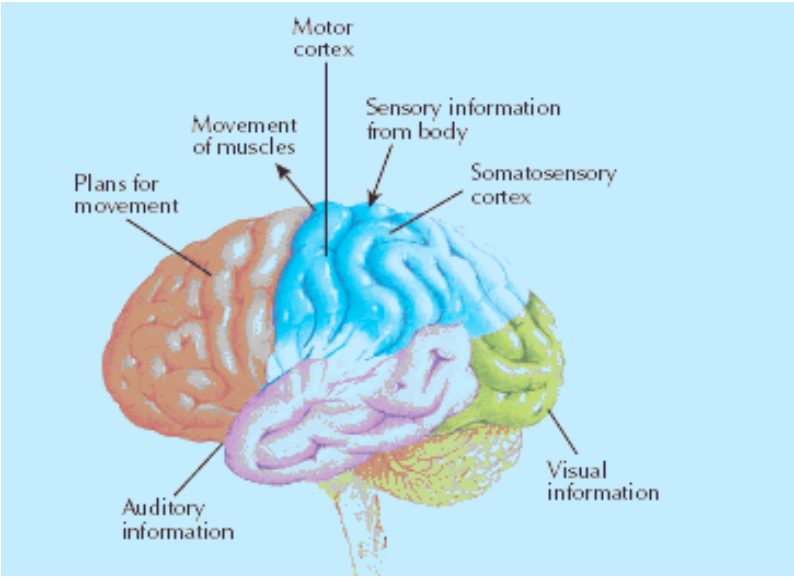
With your guidance, students can integrate separate verbal and pictorial models that they develop. Your verbal explanation of important information combined with the visual representation in your materials can lead to an integrated mental model.

2. Use visuals during review sessions.

The goal of review sessions is to solidify the structure of information and to give students the opportunity to complete the mental models they have built. As a student studies a topic and develops a mental model they may not be able to finalize that model on their own, so effective visuals used during reviews can help students do that.

Figure 12, showing the sensory areas of the brain, highlights key physical features, organizing that information in a summary way. It can assist a student to quickly review and recall the vocabulary and physical relationships.

Figure 12: Visual that Organizes Information by Summarizing



An effective instructional technique is to provide students with advance organizers that preview new information in a simple and high-level way. If a student were to review Figure 12 before studying a new chapter in the textbook, the visual could act as a simple model to help the student organize all the new information in the chapter.

3. Use visuals for assignments and when assessing learning.

Since recall and transfer of information are the result of mental model development, assignments and assessments should trigger recall, elicit students to represent how they understand the organization of information, or to engage in high-level thinking activities. You as the instructor, in assessing students' understanding, can then correct any gaps or errors in students' mental models.

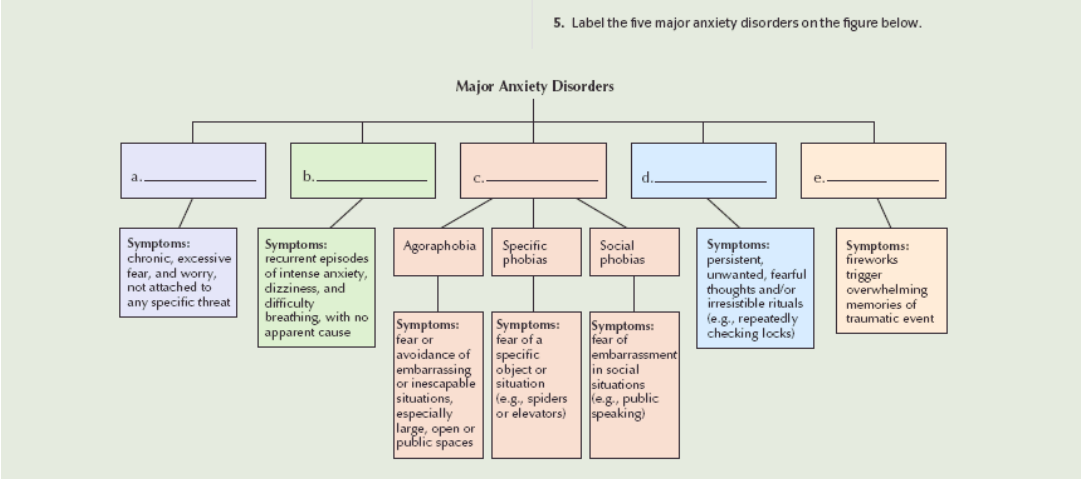
For example, students could be asked to identify examples of concepts in visuals. Figure

13 could be used to assess students' recognition and description of different geologic formations or processes.

Figure 13: Use Visuals to Assess Students' Ability to Recognize or Describe

Figure 14 emphasizes the organization of information as it assesses students' understanding. If visuals help to teach by clarifying knowledge structures, those structures should be used during the assessment of learning as well.

Figure 14: Use Visuals to Assess Students' Ability to Describe Understanding



When students develop mental models of information they can recreate the structure of that information, 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 interpreting, for predicting, and for problem solving. For instance, Figure 15 includes a question that asks students to make predictions based on features in the photograph. This type of visual is a feature of chapter summaries within Wiley Visualizing, prompting students to reflect on the concepts from the previous chapter. They are required, cognitively, to apply a mental model they built while studying the chapter to a new problem situation.

Figure 15: Use Visuals to Assess Students' Higher-Order Abilities

4. Use visuals to situate learning in authentic contexts.

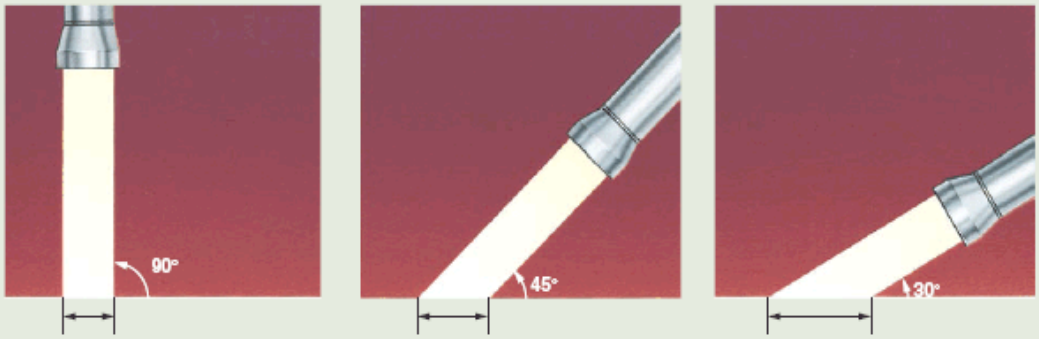
Learning is made more meaningful when a student can apply facts, concepts, and principles to realistic situations or examples, or if they see a connection to their experience and the new information. Familiarity leads to an increase of germane cognitive load, the productive effort that students put forth to build a mental model.

Visual analogies connect familiar objects with new information. Figure 14 displays an example of a visual that acts as an analogy.

Figure 16: Visuals Can Present New Information Through Analogies

Insolation and Sun angle FIGURE 3.10

The angle at which the Sun's rays strike the Earth varies from one geographic location to another because of the Earth's spherical shape.



1 unit of surface area
One unit of light is concentrated over one unit of surface area.

1.4 units of surface area
One unit of light is dispersed over 1.4 units of surface area.

2 units of surface area
One unit of light is dispersed over 2 units of surface area.

A Sunlight (represented by the flashlight) that shines vertically near the Equator is concentrated on the Earth's surface.

B and C Toward the poles, the light hits the surface more and more obliquely, spreading the same amount of radiation over a larger and larger area.

Using visuals of familiar objects to explain new, unfamiliar details about those objects also makes information meaningful. This can be particularly important when teaching abstract principles or concepts. Real-world examples or applications of those abstract principles or concepts can make them more meaningful. Wiley Visualizing texts have visual features that attempt to connect new information with how that information is applied by professionals in realistic settings. Figure 17 displays one of these features entitled "What a Geographer Sees" from *Visualizing Physical Geography*.

Figure 17: Visuals Can Connect New Information to Realistic Settings

5. Use visuals to encourage collaborative meaning making.

Visuals can be used as the centerpieces of collaborative activities, requiring students to study, make sense of, discuss, hypothesize, and make decisions regarding the content of the visual. Students can work together to interpret and describe diagrams, photographs, maps, or combinations of these. More complex activities might involve scenarios or projects that require groups of students to use visuals to solve problems, conduct research related to the topic, or work through case studies. Visuals could be part of what they use

during these types of activities or they might be what they produce as deliverables.

Effective collaboration, however, is a complex skill in and of itself, so these types of activities are not recommended when students are new to a subject and are devoting most of their cognitive load to understanding the information. If your students have a more advanced grasp on the subject matter, collaboration can help them clarify or expand their understanding of information, facilitating the building of integrated mental models. Collaborative groups often are required to practice interactive processes such as giving explanations, asking questions, clarifying ideas, and arguing and defending ideas.

6. Assign student 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. This applies especially to the Organizational and Explanative visuals in the textbook. The whole purpose of these types of visuals is to present information and they should be integrated with text. If students are trained to just read a textbook and are accustomed to instructionally-ineffective visuals, then they may not pay sufficient attention to them. This recommendation will help students select important and relevant information and not pass it by.

Conclusion

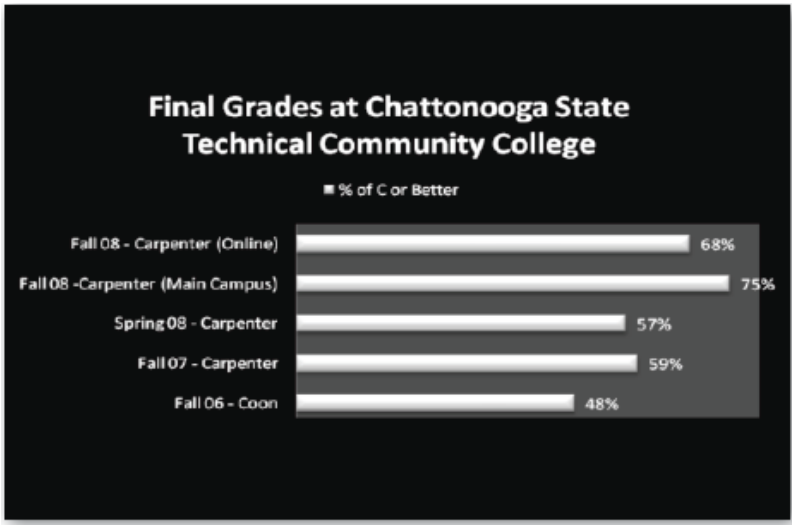
Effective use of visuals integrated with text can improve the quality of learning from textbooks by supporting the cognitive processes by which all people learn. The use of visuals helps build mental models by directing attention to important information, organizing that information in a meaningful way, and integrating verbal and pictorial models into comprehensive mental models. The two media used together can reduce unnecessary cognitive load on learners and increase students' engagement with the content.

Wiley Visualizing draws upon empirical research on the use of visuals and makes effective use of them to support learning. This reliance on research to design the instructional messages in textbooks speaks strongly of the quality of these texts, and the data tracking student success using these texts shows significant, measurable improvement in student outcomes.

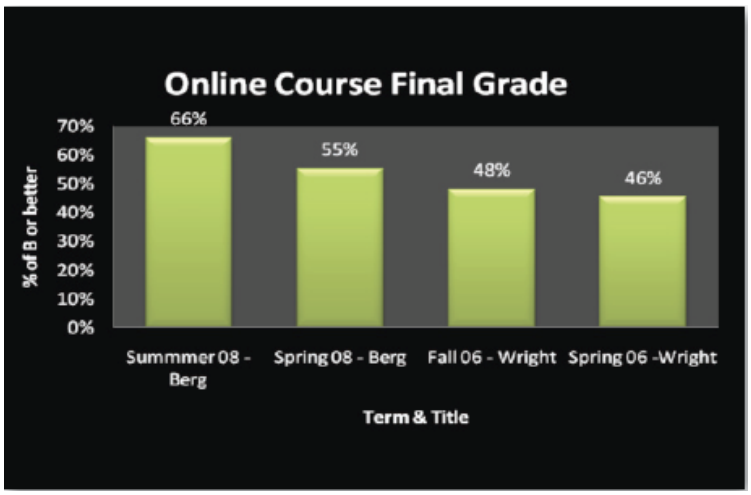
Appendix: Additional Data Showing the Impact of Visualizing on Student Outcomes

Chattanooga State Technical College
John Haworth and Donna Seagle at Chattanooga State Technical Community College had the same experience using *Visualizing Psychology* and WileyPLUS. "Our qualitative information from our students showed that they liked the text and WileyPLUS and were using them as study aids" says Haworth. The number of students completing the course with a C or better increased by 23% when the school adopted Visualizing.

Chattanooga State Technical Community College performed a correlation analysis between how students did on WileyPLUS and how well they did overall in the class. "Our correlation shows that when we adopted *Visualizing Psychology* and Wiley-PLUS we had a significant increase in grade average" explained Haworth. "There is a strong positive relationship between scores in WileyPLUS and Final Grade, when using a Wiley Visualizing textbook."



Kirkwood Community College
Keith Hench teaches Environmental Science at Kirkwood Community College. He realized a 20% increase in students receiving a B or better while using Berg, *Visualizing Environmental Science* in the online course.


Online Course Final Grade
% of B or better
70%
60%
50%
40%
30%
20%
10%
0%
66%
55%
48%
46%
Summmer 08 - Berg
Spring 08 - Berg
Fall 06 - Wright
Spring 06 -Wright
Term & Title

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