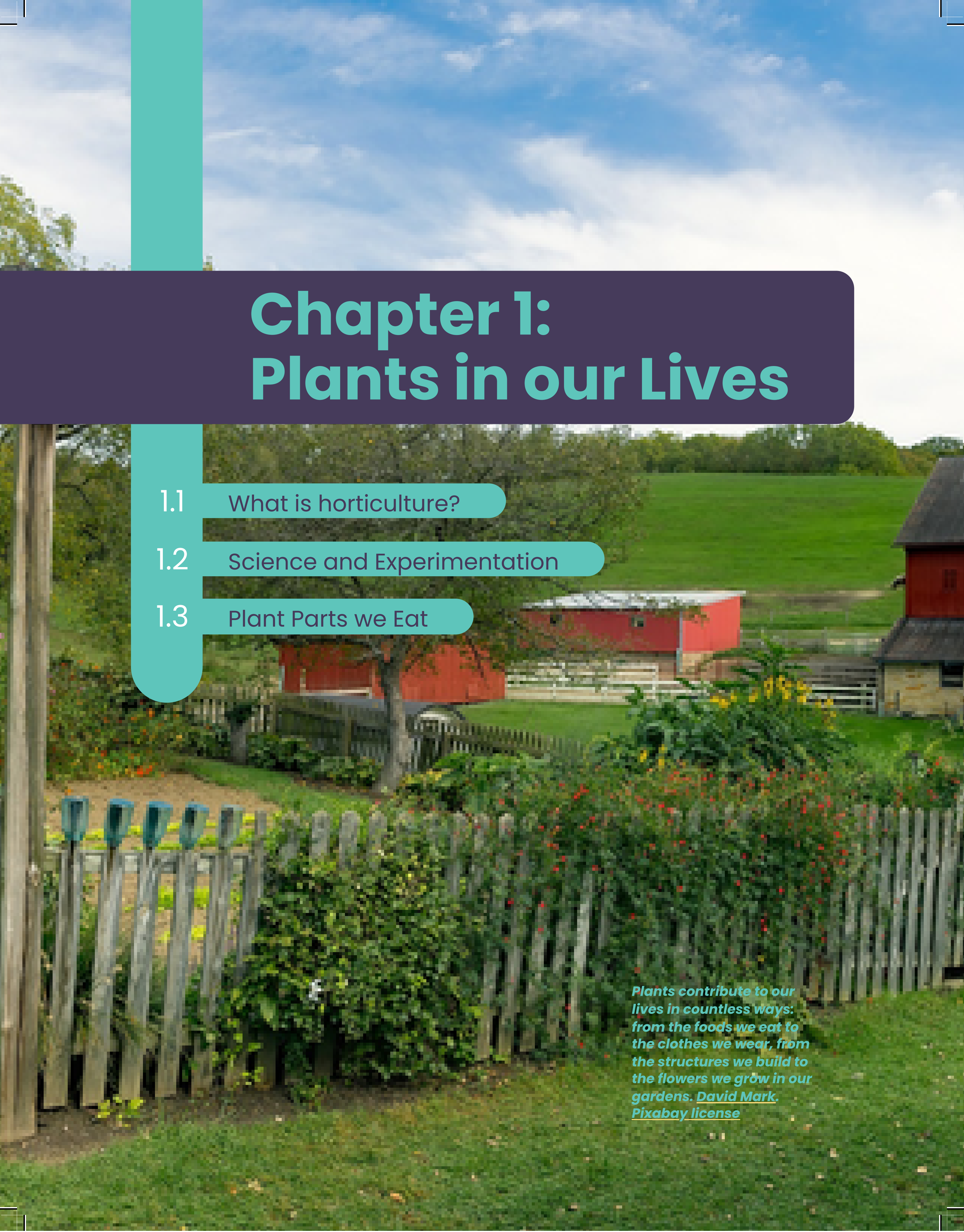
Table of Contents

Design sample A

A chapter with content examples for the following:

1. Outline
2. Introduction
3. Learning objectives
4. Content opener image
5. Review Activity
6. Key terms list
7. Sidenote (generic)
8. Case Study
9. Bibiography



Chapter 1: Plants in our Lives

Plants contribute to our lives in countless ways: from the foods we eat to the clothes we wear, from the structures we build to the flowers we grow in our gardens. David Mark. Pixabay license

In Chapter 1, you'll discover what horticulture is and how it relates to other disciplines that involve the cultivation of plants, and take a deep dive into the different types of scientific experimentation. Then you'll explore some of the plant parts that you eat, so you can start thinking about the plants that are all around us and how we use them in our daily lives.

By the end of this chapter, you will be able to:

- → Define horticulture and describe its disciplines and sub-specialities.
- → Apply the principles of experimental design to your own experiments in this course and in daily life.
- → Use biological language to describe the parts of the above-and below-ground plants parts that contribute to your diet.

1.1 What is horticulture?

LEARNING OBJECTIVES

By the end of this section you will be able to:

Define the term horticulture.

Describe disciplines related to horticulture.

Describe some of the specialties in the field of horticulture.

Horticulture and related disciplines

Horticulture

Horticulture is the art and science of the development, sustainable production, marketing, and use of high-value, intensively cultivated food and ornamental plants. The word is derived from the Latin words hortus (garden plant) and cultura (tilling the soil). Horticulture includes ornamental and food plants that are grown with intensive and individualized care, and often in a small space rather than in an expansive field.

Table 1.1 **Horticultural plants overview**

Ornamental plants	Food plants
Flowers, ornamental shrubs, ornamental trees, turfgrass, native grasses, and forbs are all horticultural plants.	The plants producing the vegetables and fruits we eat are all horticultural plants.
They all have a fairly high value per acre.	They have a high value per acre and, like the ornamental plants, require intensive management.

Agronomy

Agronomy is another term commonly used in reference to food production, and refers to the management of plants grown over large areas with less intensive management than that normally provided to garden plants. Its etymology is from the Greek agros (= field) and nomos (~management). Agronomy fields are larger than gardens, so the plants grown in these fields are less intensively and individually managed than those in most gardens. It is estimated that a single agronomy farm produces food for over 150 people.

Extensive agronomic crop production requires fewer person-hours of management per acre than intensive horticultural production, which requires more person-hours of management. In contrast, agronomy refers to management of field crops such as cereals (e.g. corn, wheat, rice, barley) and legumes (e.g. soybeans, common beans, peanuts, alfalfa) and a few other high-acreage crops, like cotton. These are typically plants that have a low dollar value per acre, and in many cases the crops are used for animal feed rather than for direct human consumption. These are grown over extensive areas with less intensive management, or at least with fewer people per acre involved in managing the crop than would be typical of horticultural crops.

Agronomy refers to large scale production of commodity crops like grains.

Forestry

Forestry is the science or practice of propagating, planting, managing, and caring for forests, and of harvesting products from them. Forestry, which focuses on trees for building materials, pulp, and paper, is a third type of plant-production system, considered separately from horticulture and agronomy, and is not covered in this course.

Agriculture

Agriculture is the science or practice of farming, including cultivating soil for growing crops and rearing animals to provide food, fiber, and other products. The term is derived from the Latin ager (field) and cultura (tilling the soil). While the Latin root means "field" and implies a larger land area than "garden," "agriculture" typically encompasses both horticulture and agronomy. For instance, the University of Minnesota College of Food, Agricultural and Natural Resource Sciences (UMN CFANS) includes both the Department of Horticultural Science and the Department of Agronomy and Plant Genetics. There is, however, no hard, distinct line separating horticulture and agriculture. While horticulture deals with plants you might find in a garden, it's common to find those same plants (like vegetables and fruits) grown in large fields and harvested in volumes sufficient to supply grocery stores. Other ornamental garden plants, such as annual and perennial flowers, ornamental shrubs, and trees, are planted

Agriculture encompasses all farming practices, including this large-scale strawberry operation in Argentina. Photo from World Bank Photo Collection. CC BY-NC-ND 2.0.

in extensive, designed landscapes. Field corn used for animal feed is considered an agricultural crop, while sweet corn is considered a horticultural crop, yet they are the same species of plant.

NOTE

Vocabulary

Horticulture: Requires intensive management on fewer acres and higher human input per acre, and produces a higher value per acre. Includes ornamental plants and whole foods (like those found in the produce aisle).

Agronomy: Requires extensive production on more acres with lower human input per acre, and produces a lower value per acre. Includes animal feed and processed food ingredients, (such as oil, protein, sugar, and starch).

Agriculture encompasses both horticulture and agronomy.

Domesticated plants and wild plants

The plants grown in horticulture and agronomy are usually domesticated rather than wild, meaning that humans have selected them, intentionally or unintentionally, for particular characteristics such as adaptation to cultivation in a garden, large showy flowers, or large, sweet fruits. You will learn about the science of plant improvement and domestication in the section on plant breeding.

Because garden plants are grown in modest-sized spaces, the gardener can provide intensive management such as a complex garden design, special care for the soil and plant health, and regular weed control.

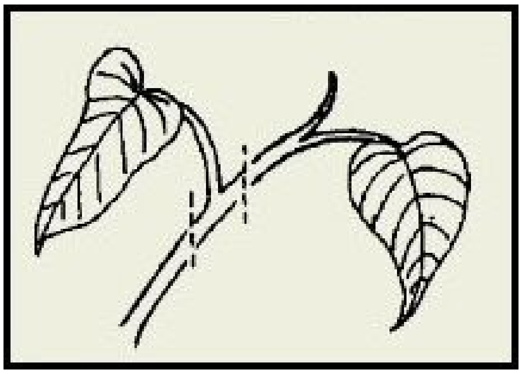
In general, then, "horticulture" refers to domesticated ornamental and food plants that humans grow in modest-sized spaces where they provide intensive management.

Horticulture and plant propagation

Science of plants

Plant science explores how a plant is put together and how its parts work together during a plant's life cycle — from seed to seed.

Throughout this course, you will study plant structure, growth, and reproduction, applying what you learn to plant propagation practices in the lab portion of this course.



Sketch of two leaves attached to a stem.

CASE STUDY

Horticulture specialties

Within the industry, and also within universities, horticulture is often subdivided into specialties according to the use of the plant or plant part that is produced. The Market Analysis: 2019 Census of Horticultural Specialties webinar demostrates these six of these specialties:

1. **Breeding and genetics:** development of new cultivars (cultivated varieties) of plants for production via sexual reproduction.
2. **Floriculture:** production and marketing of plants valued for their flowers and propagated by seed or by cuttings.
3. **Landscape** horticulture: production, marketing, and maintenance of plants used in designed and managed landscapes.
4. **Olericulture:** production and marketing of plants or plant parts valued for culinary use as vegetables.
5. **Pomology:** production and marketing of plants or plant parts valued for their culinary use as fruits including nuts.
6. **Post-harvest management:** development of practices that maintain quality and prevent spoilage of harvested horticultural plants or plant parts during storage and transportation.

Science in our lives

For many of you, this course might be the only science course you take. The course therefore goes beyond the subject of plants to help you to see the world as a scientist might see it. Science is a systematic enterprise that builds and organizes knowledge in the form of testable explanations based on observations and predictions.

You will learn how to propagate plants, and learn about plant structure and function. But perhaps more importantly, you will learn about science as a way of understanding and appreciating the world around you — in this case, the horticultural world around you.

REVIEW ACTIVITY

What is the difference in meaning between the Latin words hortus and agros?

Differentiate among horticulture, agronomy, and agriculture.

In general, which would you expect to provide the highest value per hour of human management: horticultural plants like vegetables, or agronomic commodity crops like corn?

1.2 Science and Experimentation

LEARNING OBJECTIVES

By the end of this section you will be able to:

Describe why science is considered a discipline of philosophy.

Summarize the four basic types of experiments.

Apply the principles of experimental design in this course and in your daily life.

Thinking about science

The primary goal of this section is to help you think about the nature of science. You might be taking this course to fulfill an undergraduate requirement for a biology course with a lab. This course fulfills that requirement because we investigate the process behind using science as a way of learning about the natural world around us. If you're starting down the path to becoming a plant scientist, understanding the nature of science will be essential for you in your career

Regardless of whether you're going to pursue a career as a scientist, now is a good time reflect on the nature of science, and to understand how scientific thinking can become a strategy for resolving many issues that you confront during daily life.

NOTE

Watch this video about connecting science and experimentation to real life: One or more interactive elements has been excluded from this version of the text. You can view them online here: https://open.lib.umn.edu/horticulture/?p=94#oembed-1

Scientific inquiry

While "science" is a word commonly used in our culture, in popular use it is rarely spoken of as a philosophy. By identifying science as a philosophy we are taking an epistemic view, one focusing on how knowledge is acquired.

At its core, science is a mode of inquiry: a way of acquiring new knowledge about the world around us and a strategy for understanding the inner workings of elements in that world. Scientists believe that if we follow the principles of this philosophy we will continue to expand our knowledge about how things work in the world around us. This systematic approach is called the "scientific method."

There are two key steps in the scientific method:

- Hypothesis building through reflective observation.
- Hypothesis testing through experimentation.

A "hypothesis" is a question or proposed explanation made on the basis of limited evidence and used as a starting point for experimentation. Experimentation is commonly equated with science—rightly so, because hypotheses evaluated on the basis of evidence generated through experiments. Experimentation, however, isn't the whole story. Science—including the development and testing of new hypotheses—is also a creative endeavor.

NOTE

Watch this video about scientific inquiry: One or more interactive elements has been excluded from this version of the text. You can view them online here: https://open.lib.umn.edu/horticulture/?p=94#oembed-2

Scientific inquiry has generated a vast body of knowledge about the world around us. Your school science classes might have required you to memorize facts and relationships, and pay attention to detail. Sometimes such memorization leads students to believe that science is just an accumulation of facts rather than the process behind discovering all of that information.

Scientific discovery builds on what is already known. Even the most accomplished scientists initially approach a problem by learning what is already known. Armed with that information, they then apply their own creativity to form new hypotheses about something they have observed, and design experiments to test those hypotheses. They also communicate their results publicly so that others can benefit from their work and have the opportunity to challenge conclusions. In this way, science builds on itself.

The foundational knowledge you learn in science classes prepares you to develop and test hypotheses and to make new discoveries of your own. While a good memory may help you pass a science classes, you will absorb a body of knowledge more effectively when you learn how facts fit and work together in systems rather than learning through the brute force of memorization.

In this section we work from the point of view that science is a way of acquiring knowledge—a mode of inquiry—and that this mode of inquiry follows a process called the scientific method. Those who follow the philosophy of science:

- Use it to understand how the natural world works.
- Start by learning what is already known.
- Carefully observe the subjects of their scientific inquiry and look for details about form, function, and interaction with the environment.

- Develop hypotheses about the inner workings of natural phenomena not yet understood.
- Test their hypotheses by making observations, conducting experiments and collecting and evaluating evidence.
- Communicate with others about their hypotheses, experiments, and the outcomes of their studies so that others can repeat, validate, and build upon their work.

Although science is typically used to understand how the natural world works, it is also regularly applied to the development of new technologies that are based on these natural phenomena and to the solving of problems associated with the natural world.

Putting the scientific method to work

As noted, the scientific method relies on building hypotheses and then testing them through experimentation. In the lab section of this course you will develop hypotheses about the effects of various treatments on propagation success and then conduct experiments to test those hypotheses. Because experimentation is such a key component of the scientific method, we'll spend time characterizing and examining four types of experimentation and explore whether they are part of the scientific method. While each is valuable when applied in the right circumstances, only one clearly follows each step of the scientific method to uncover new knowledge about the natural world.

Types of experiments

The types of experimentation we will cover are:

- Demonstration
- Evaluation
- Exploration
- Discovery

Demonstration experiments

Demonstration experiments are a classic method used in educational settings to help students learn and understand known relationships already discovered by others. Learners will usually have had prior exposure to the relationships through preliminary observations, lectures, reading, and discussions, and will have some sense of what the experimental outcome might be.

Many experiments conducted in lab courses are demonstration experiments. Photo by Salish Sea Expeditions. CC BY-NC-ND 2.0

Good demonstration experiments actively involve the learner, who manipulates the experimental materials, applies the treatments, and observes the outcomes, then gathers, analyzes, and interprets the resulting data. Poor demonstration experiments, in contrast, make learners only passive witnesses to something done by an expert at the front of the classroom.

In the plant propagation labs for this course, you will be actively engaged in demonstration experiments. Although you won't be creating new knowledge, the knowledge will likely be new to you. The hands-on experience of conducting the experiments will help you to learn the concepts more effectively than if you only read a textbook or listened to a lecture. The techniques you learn and use in demonstration experiments often contribute to the learning experience as much as the relationships revealed at the experiment's conclusion. Employing these techniques will help you gain an understanding of many biological functions, such as the production of adventitious roots and mechanisms for seed dispersal.

While demonstration experiments are valuable for actively learning a body of scientific knowledge previously discovered and communicated by others, the experience is specifically orchestrated for teaching and learning, not for the discovery of new information. Yet since the knowledge is new to the learner, it can still bring the joy of personal discovery and a sense of accomplishment.

In summary, demonstration experiments:

- Are designed for teaching and learning.
- Address relationships that may be new to you, but are otherwise known.
- In their best forms, actively involve the learner.
- May emphasize experimental techniques, in addition to outcomes, as part of the learning experience.
- Are not the types of experiments that are at the core of practicing science as a way to uncover new knowledge.

Evaluation experiments

Evaluation experiments are designed to help us make decisions, and to choose from a number of options. They might, for instance, help us determine the efficacy of a new treatment relative to a known treatment, or decide on further experimentation. An evaluation experiment will highlight a compound, a technique, a piece of equipment, or an organism, and will include a control and/or other alternatives.

Evaluation experiments are common in horticultural and agronomic research, where the purpose of the experiment is to identify, for example, the best cultivar, production method, pest control, fertility regime, or light intensity for growing a crop. Correct experimental design is crucial for assuring that conclusions from the experiment are meaningful and credible.

These experiments are typically used in the development of new technologies to identify the best method for the desired purpose (e.g., which pesticides are effective against the target insect, but not harmful to non-target insects). They are not used to discover new knowledge about how the world works, as they typically don't advance our understanding of the natural world. The information from an evaluation experiment might, however, point the way to additional experimentation that does help us discover new knowledge. This is particularly true if the outcome of an evaluation experiment is unexpected or novel.

This field experiment is testing different living mulches between rows of strawberries. Photo by University of Minnesota West Central Research and Outreach Center.

In summary, evaluation experiments:

- Are used to help in decision-making.
- Help users choose a winner or determine efficacy relative to other alternatives.
- Are commonly used when evaluating and recommending horticultural production methods.
- Can be useful in solving problems and developing technologies.
- Require proper experimental design (e.g., comparison to a control) for credibility and meaningfulness.

Exploration experiments

Some scientists specialize in observing and cataloging nature, and some, like members of the group that discovered a new species of hominid, Homo naledi in a South African cave, aggressively search for previously unknown phenomena. In the botanical realm, such scientists study the diversity of organisms within habitats, discover new species, or are in other ways very skilled in "seeing" nature. Explorer-scientists recognize and appreciate detail and can identify the enormous diversity among plants by comparing characteristics that might be overlooked by others. They may also have the capacity to recognize possible interrelationships among organisms and with habitats, making their work particularly important to science. They might notice, for instance, that a particular species of plant is commonly found in wet areas but not in dry, or that a particular vegetable tastes sweeter when grown at higher altitudes than when grown closer to sea level. They don't confirm the cause of these relationships, but are the first to notice them.

This scientist is collecting plants in Ecuador to identify unknown species and to determine relatedness to other plants. Photo by Dr. Eric Tepe, University of Cincinnati.

Explorers' observations are essential to stimulating the development of sound, testable hypotheses. The possible relationships they propose must be tested to determine whether those relationships actually exist, or are artifacts of other effects. Explorers help develop hypotheses, but the work of exploration, cataloging, and seeing possible relationships don't prove or disprove the hypotheses or necessarily generate new knowledge about relationships. The work does, however, result in new information about the existence of the object or phenomenon itself. An exception is exploration done to test a hypothesis, such as a mission to test the hypothesis that a particular type of ecosystem is required for reproduction of a particular plant species.

Scientists must resist jumping to conclusions based on exploration and observation alone. If you see two people together many times, for example, you might conclude that they are a romantic couple, when in fact they are brother and sister. Relationships hypothesized as a result of exploration and observation must be experimentally tested before they are accepted or rejected.

Exploration experiments uncover new things, many of which can be exciting and eventually change our view of the world. While one of their greatest values is that they lead to the development of new and stronger hypotheses about how the world works, they go so far as to test those hypotheses or fully engage in the cycle of knowledge generation associated with the scientific method. Additional experiments based on this new information are required to put this new information in context and to advance our understanding of how the natural world works.

In summary then, exploration experiments:

— Focus on detailed observation of organisms and habitats.

— Increase our knowledge of the natural world.

— Identify potential relationships that need to be tested.

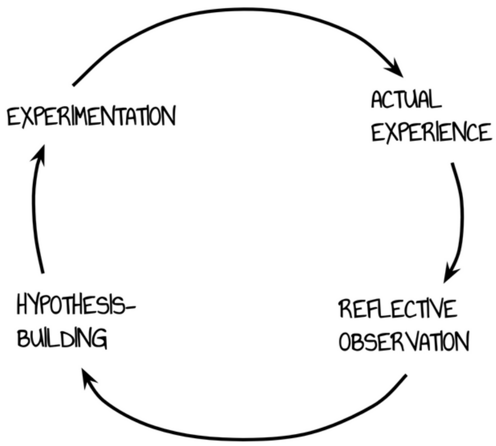
— Are essential to sound and testable hypothesis-building.

Discovery experiments

Discovery experiments are central to the use of the scientific method in tasks ranging from problem solving to the discovery of new knowledge. They focus on uncovering new relationships and solving problems, follow the scientific method, test hypotheses and their predicted outcomes, and utilize a careful design in order to maintain meaningfulness and credibility.

The similarity between the scientific method and Kolb's Experiential Learning Cycle is not an accident. The scientific method is a practical strategy based on how we sense and experience the world around us and used to solve problems encountered during those experiences.

The diagram above illustrates a combination of the scientific method and Kolb's four-step experiential learning, describing a cyclic process for solving problems that can be applied to disciplines as diverse as molecular biology, global warming, and even appliance repair. While you might initially think that appliance repair doesn't belong in that list, the difference is one of application, not method. Though far removed from the esoteric scientific discoveries we associate with scientific method, appliance repair follows the same steps. Appliances are often, and quite literally, boxes, where you don't know what is going on inside. But what's going on inside is knowable, and through that knowledge comes repair.



The scientific method is a great example of the experiential learning theory. Illustration by Emily Tepe.

The learning/problem solving/scientific process could theoretically start anywhere in Kolb's cycle. But it will likely start with a problem that needs to be solved, something you don't understand but would like to know more about. You become aware that there is a problem or that you lack understanding because you have an experience where you observe something and then step back and said, "I wonder how that works," or perhaps, "why is that broken?" Through observation you develop a sufficiently adequate description of the problem to start doing some research on what is already known.

With a good description of the problem in hand, you can begin to review what is known through the work of others, and think about what might be going on in your situation and how your new understanding can be applied to the problem. This is "reflective observation." It isn't just sitting back and thinking in a vacuum. You need raw material for your mind to work on, and that only comes through the tough task of gathering and engaging with the background information. There is a very important quiet phase in this process when you let your mind assemble and sort through ideas until alternatives begin to emerge that might lead to a solution. Talking with others and sharing ideas is an important part of this quiet phase.

Sometimes the alternatives are no- brainers (blown fuse?), and sometimes they're more creative (residue from the wrong detergent gunking up the water level sensor?). Regardless of their simplicity or complexity, these become hypotheses that need to be tested. The hypothesis-building stage includes both a statement of how something works or why it isn't working, and predictions about what might happen if the hypothesis is true. In appliance repair, for example, the prediction will likely be that the appliance will function normally. In horticultural molecular biology, it might be that you will see accumulation of a particular type of fatty acid in the cotyledons.

You put the hypothesis to the test by designing an experiment that assesses whether your predictions were right. If the outcome doesn't match your prediction, you reject the hypothesis (the fuse was ok, so that wasn't the problem). If the outcome does match your prediction, you tentatively accept the hypothesis pending further observation (when the fuse was replaced the washing machine worked again, so it might have been a blown fuse, but on the other hand maybe it was just because the motor had time to cool down). As with evaluation experimentation, experimental design is important in assuring that the conclusions from the experiment are meaningful and credible.

Experimentation leads to new experiences and an incremental increase in knowledge, and then the cycle begins again.

In summary, discovery experiments:

- Focus on uncovering new relationships and solving problems.
- Follow scientific method.
- Test hypotheses and their predicted outcomes.
- Utilize a careful design in order to maintain meaningfulness and credibility.

Summary

Of the four types of experiments, only the discovery experiments are core to the process of science in the narrow sense of being a way of acquiring new knowledge. The other three types of experimentation are still important; demonstration and evaluation experiments are valuable for learning and decision-making and for technology development, and exploration experiments are essential for developing testable hypotheses. But discovery experiments are core to science.

Remember: the methodology of effective washing machine repair, when applied to what is unknown about the physical world, is the methodology of science. It's not esoteric; it's good appliance repair.

You might argue that, when applied to a broken washing machine, a discovery experiment results in knowledge that is probably already known by those skilled in appliance repair, so it isn't really new knowledge about how the world works. That's a fair criticism. Use of the scientific method can result in new knowledge about how the world works, but whether it uncovers new knowledge depends on the object of experimentation.

REVIEW ACTIVITY

Some questions about the text above:

Question 1

Question 2

Question 3

Experimental design

The methods for designing experiments are carefully studied and often discipline-specific. Methods used in molecular biology, for instance, will be somewhat different from those used in chemistry or in field evaluations of horticultural plants. There are, however, some generalizations we can make about good experimental designs.

Emphasize comparisons

Experiments include more than just one treatment. “Treatment” refers to the factor that you are varying in your experiment—for example, different cultivars of tomato, different fertilizers, or different amounts of light. Experimental designs incorporate comparison of treatments. You usually compare the treatments to one another and often to a control, which is either the application of no treatment or the application of a customary or standard level of treatment.

If you grow a particular type of tomato in your garden, and find that it produces tasty fruit, would you declare it to be the best tomato variety you could grow? Certainly not. You couldn’t even say with certainty that it was the best tomato variety you have ever grown (unless it is the only one you have grown). Next year, however, you could grow that tomato as your control, and grow two other varieties that your neighbors like, and compare fruit quality (appearance, flavor, yield, sugar content). You could then say something definitive about the three tomato varieties because you have compared them to each other after growing them next to each other in the same year and environment.

Replicate treatments

The same treatment is applied to more than one “experimental unit”—the object that receives the treatment. In the example above, the tomato plant is the experimental unit, and you would perhaps plant two or three seedlings of each tomato variety rather than just one. Think of a treatment as something like a fertilizer spread on a patch of land. The patch of land is the experimental unit, while the fertilizer is the treatment.

By applying the treatment to more than one experimental unit you can estimate the variation you get when two experimental units are treated the same, and compare this to the variation when experimental units are given different treatments. If the treatments actually differ in their effectiveness, you would expect the variation between experimental units given different treatments to be much greater than the variation between those given the same treatment. This is one of the fundamental ways in which experiments are statistically analyzed and treatments declared significantly different or not.

Randomize treatments

Once you know how many treatments you are going to apply, and how many replications you want, the product of these two quantities (# treatments × # replications) equals the number of experimental units you need. For instance, if you have three fertilizers you want to test, plus a control, you have four treatments. If you want three replications of each treatment, then you 4 treatments x 3 replications = 12 experimental units or patches of land where you will apply the fertilizers. The treatments will be randomly assigned to each experimental unit (patch of land). This is done using a random number table and is not just haphazard picking. Randomization helps minimize any bias you haven't recognized in advance and controlled for in other ways.

REVIEW ACTIVITY

What are two types of control treatments?

Does increasing the number of replications increase the number of treatments or the number of experimental units?

Can you think of an example of how randomization can protect against bias?

1.3 Plant Parts we Eat

LEARNING OBJECTIVES

By the end of this lesson you will be able to:

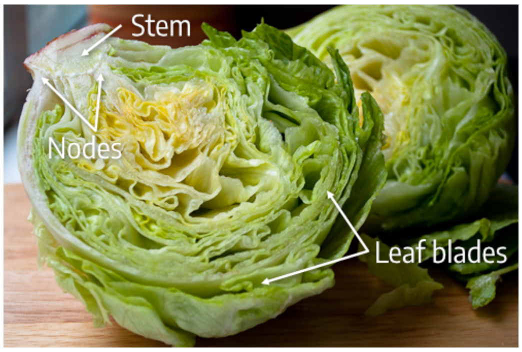
- Summarize the various above- and below-ground plant parts that contribute to your diet.
- Use the correct language of biology when identifying parts of plants.
- Appreciate the diversity of edible plant parts.

Above-ground plant parts we eat

Edible leaves and petioles

In this image of an iceberg lettuce cut in half, you can see how the leaf blades are packed and folded together tightly in the lettuce head. Lettuce is an example of a plant shoot with very short internodes on the stem. This results in a compact but leafy plant. Iceberg lettuce is a type of heading lettuce where older leaves envelop newer leaves forming a solid or semi-solid ball or head of lettuce leaves.

Romaine and leaf lettuces exhibit a more open architecture, with the leaves forming a looser head with upright leaves. Romaine lettuce has elongated leaves. There may be some tendency of older leaves to enclose newer leaves, but it is much less pronounced than in iceberg lettuce, and may be absent altogether in some of the garden types. Leaf lettuce lacks the tendency to form heads.



"Iceberg Lettuce" by Кулинарно, CC BY-NC-SA 2.0

Image by Peter Drache. Pixabay license

Lettuce leaves generally lack a petiole. The blade narrows a bit, but attaches directly to the node. A leaf lacking a petiole is called a “sessile” leaf. The point of attachment of the leaf to the stem is at a node. If you tear the leaves from a lettuce plant you are left with a short stem made up of many nodes and short internodes.

You can see in the romaine lettuce that its morphology is similar to that of the iceberg lettuce and that it has some tendency to wrap newer leaves within older. However, the nodes are a bit longer than what you see in iceberg lettuce, and that makes the node locations more apparent.

A few examples of leaf parts we eat

Modified petioles

Celery is an example of a leaf with a petiole. The parts that you eat are the petioles, while the leaf blades are often not present in the bunch of celery you purchase. If you buy a bunch of celery and pull off the large, outside petioles, inside you will find shorter petioles with the leaf blades still attached.

Celery is a geophyte (covered in a later lesson). Some of the celery petiole — the pale part at the bottom where it attaches to a node on the stem — grows underground. This part is pale because it lacks chlorophyll; the petioles were not exposed to sunlight and chlorophyll failed to develop.

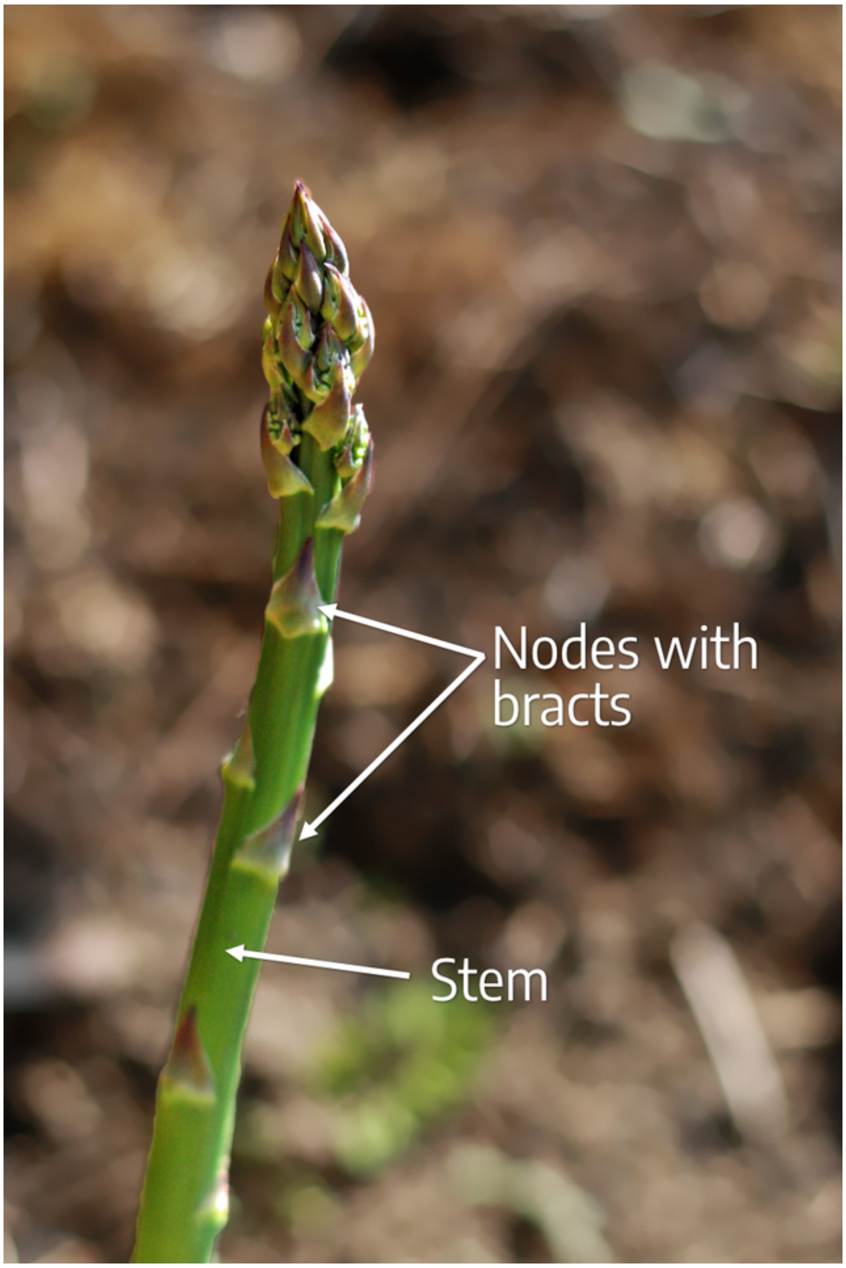
Intentionally covering the petioles to discourage chlorophyll and encourage white, tender stems is called blanching. Blanched celery is more attractive to some cooks and consumers, although it may not be as nutritious.

TIP

Watch this video on edible leaves and petioles: One or more interactive elements has been excluded from this version of the text. You can view them online here: https://open.lib.umn.edu/horticulture/?p=105#oembed-1

Edible stems

The photo below shows an asparagus shoot. You can tell it is a shoot by the regular node/internode construction of the stem. Most of the shoot is stem tissue. The triangular growth at each node is colloquially called a “bract” by asparagus growers, but it is actually a very small, scale-like leaf. If the shoots are left unharvested, branches grow from the nodes and then repeatedly branch into soft, feathery green foliage, as shown in the next photo.



Mature asparagus plant.

Asparagus shoots that are not harvested grow taller and produce branches and feathery foliage.

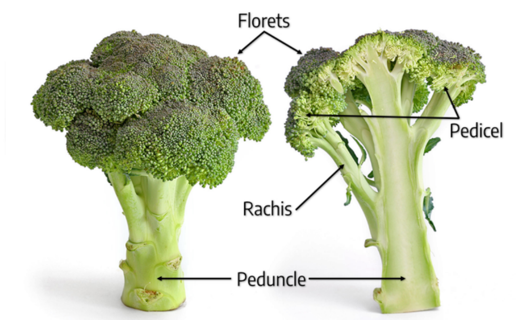


Photo by Fir0002/Flagstaffotos, CC BY-NC.

Nasturtium flowers and leaves are edible.

Edible inflorescences

Broccoli and cauliflower are eaten as immature inflorescences. The dark green exterior of the broccoli inflorescence is made up of tight flower (or floret) buds that have not yet opened. The term "floret" is often used for the name of a flower born on a complex inflorescence.

Inside the inflorescence, the flower buds are supported by short, thin pedicels. The pedicel is attached to a series of increasingly thick internal stalks which make up the rachis structure of the inflorescence. The rachi all connect to the main stem of the inflorescence, which is the peduncle, and which then attaches to a node on the stem. The peduncle is the bit of the stalk that extends from the node where the inflorescence is attached to where the first rachis branches off. Above that, the central axis of the inflorescence is also called the rachis. An inflorescence can contain many rachi.

These plant parts may look similar, but they're in different positions in the inflorescence. The terminology is important for distinguishing between parts, making observations, and describing different aspects of the plant, especially for data collection in experiments.

Nasturtiums, shown above, are also an inflorescence. They can be used as a colorful addition to a salad, and have a pleasant spicy flavor. In this case we are eating a single open flower, instead of a mass of immature rachi, pedicels, and florets as we are with broccoli.

It's important to remember that not all flowers are edible, and some are even poisonous. If you're interested in edible flowers, you must learn which species are safe to eat and how to identify and prepare them.

REVIEW ACTIVITY

Cauliflower.
Cauliflower has very tight flower clusters, but otherwise has a very similar morphology to broccoli. Can you identify the pedicel, rachis, peduncle, and florets?

Chinese cabbage.
This Chinese cabbage has a morphology similar to that of romaine lettuce. Can you identify the stem, nodes, and leaf blades?

KEY TERMS: CHAPTER 1

These are the important terms from this chapter to be sure to know. You might also find these in later chapters.

AGRICULTURE: The science or practice of farming, including cultivation of the soil for the growing of crops and the rearing of animals to provide food, wool, and other products.

AGRONOMY: The science and technology of producing and using plants for food, fuel, fiber, and land restoration on an extensive scale. The value per acre is lower than for a typical horticultural crop.

ASEXUAL PROPAGATION: A form of propagation that results in plants with genetics identical to those of the parent plant.

BRACT: A modified leaf or scale, usually small, with a flower or flower cluster in its axil.

BULB: A specialized, underground organ with a short, fleshy stem axis (basal plate) enclosed by thick, fleshy scales modified for storage.

CONTROL (IN AN EXPERIMENT): Used to verify or regulate a scientific experiment by conducting a parallel experiment or by comparing with another standard.

DEMONSTRATION EXPERIMENT: A method for actively learning the body of scientific knowledge that has been previously discovered and communicated by others; specifically orchestrated for teaching and learning, not for the discovery of new information about the world around us.

DISCOVERY EXPERIMENT: A method focused on uncovering new relationships and solving problems, following the scientific method, testing hypotheses and their predicted outcomes, and utilizing a careful design in order to maintain meaningfulness and credibility.

EVALUATION EXPERIMENT: A method typically used during the development of new technologies to identify the best products for a desired purpose (e. g., which pesticides are effective against a target insect, but not harmful to non-target insects), but not used to discover new knowledge about how the world works, and thus not typically advancing our understanding of the natural world. Used to pick a winner from among a number of options.

EXPERIMENTAL DESIGN: The process of planning an experiment to test a hypothesis.

EXPERIMENTAL UNIT: The entity to which a specific treatment combination is applied.

EXPLORATION EXPERIMENT: A method focused on detailed observation of organisms and habitats, used to increase our information about the natural world and to identify potential relationships that need to be tested, and essential to the building of a sound and testable hypothesis.

FLORICULTURE: Discipline of horticulture concerned with the production and marketing of plants valued for their flowers.

FORESTRY: The science or practice of propagating, planting, managing, and caring for forests; includes harvesting.

FRUIT: Ripened ovary together with the seeds within the ovary.

GEOPHYTES: Plants with underground organs in which the plant stores energy or water. New growth begins underground, and the function of this growth is the storage of food, nutrients, and water during adverse environmental conditions.

HORTICULTURE: The art and science of the development, sustainable production, marketing, and use of high-value, intensively cultivated food and ornamental plants.

HYPOTHESIS: Scientific means of forming a question or proposed explanation made on the basis of limited evidence as a starting point for experimentation. In science, a testable statement.

INFLORESCENCE: Complete flower structure of a plant; includes the flower, pedicle, rachis, and peduncle.

INTERNODE: Stem regions between nodes in plants.

LEAF: A usually green, flattened, lateral structure attached to a stem and functioning as a principal organ of photosynthesis and transpiration in most plants.

LEAF BLADE: Broad portion of a leaf; does not include the petiole.

MONOCOTYLEDON: Seed plant that produces an embryo with a single cotyledon and parallel-veined leaves; includes grasses, lilies, palms, and orchids.

NODE: Stem region of a plant where one or more leaves attach; location of lateral buds.

OLERICULTURE: Discipline of horticulture concerned with the production and marketing of plants or plant parts valued for culinary use as vegetables.

PEDICEL: Short stalk that holds up the flower.

PEDUNCLE: Large, central stalk that attaches the rachi to the stem of the plant.

PETIOLE: Stalk by which most leaves are attached to a stem; part of the leaf structure, not the stem.

POMOLOGY: Production and marketing of plants or plant parts valued for their culinary use as fruits, including nuts; propagated by cuttings and grafting (asexual propagation).

RACHIS: Stalk of a flower that is situated between the peduncle and the pedicel.

RANDOMIZATION: Act of randomly assigning treatments to experimental units using a random number table or computer-generated randomization to help minimize any bias that has not been recognized in advance and controlled for in other ways.

REPLICATION: Application of the same treatment to more than one experimental unit.

RHIZOME: Horizontal stem growing just below the soil surface.

SCIENCE: Systematic study of the structure and behavior of the physical and natural world through observation and experiment.

SCIENTIFIC DISCOVERY: Process of scientific inquiry; builds on what is known by testing hypotheses.

SESSILE: A leaf that lacks a petiole; called a sessile leaf.

SEXUAL PROPAGATION: Form of propagation that results in plants with genetics that differ from those of the parent plants; also called seed propagation.

STEM: Supporting and conducting organ, usually developed initially from the epicotyl and growing upward; consists of nodes and internodes.

TREATMENTS: Administration or application of agents to a plant to prevent disease or facilitate growth.

TUBER: Swollen, underground, modified stems that store food.

Bibiography

- Blair, A. et al. (eds.), 2021, *Information: a historical companion*. Princeton: Princeton University Press.
- Graham, M., & Dutton, W.H. (eds.), 2019, *Society and the Internet.* Oxford: Oxford University Press.
- Floridi, L., 2014. *The fourth revolution.* Oxford: Oxford University Press.

Design sample B

A chapter with content examples for the following:

1. Focus questions
2. Summary
3. Review Activity
4. Sidenote (tip)
5. Worked example
6. Further reading
7. References

Chapter 1: Digital Information

The chapter covers key characteristics of the information age:

- How does the digital revolution change not only the amount of stored information but also attitudes toward information?
- How do the global, ubiquitous infrastructures allow for unprecedented access to information and processing power?

Information explosion

We are all familiar with how significant storage capacity is: we routinely buy smartphones with gigabytes of memory and hard drives with capacities of a couple of terabytes. The availability and affordability of such devices, and even the familiarity with these data units are a far cry from not so long ago. In the last decades of the previous century, personal computers were a new phenomenon, digital photography was in its infancy and today's social media did not even exist yet. In 1983, the Apple Lisa, the commercially failed precursor to the Macintosh, had a five megabyte hard disk and cost almost US $10,0000 (the equivalent of over US $ 25,000 today). In 1988, a FUJIX DS-1P, the first fully digital camera, had a two megabyte memory card that could hold five to ten photographs. Our need for data storage and communication has changed a lot since those heady times.

The obvious reason for this change is the explosive increase in information production that characterizes the digital era. In a process of steady growth through the centuries, human societies had previously accumulated an estimated 12 exabytes of information. By 1944 libraries were doubling in size every 16 years, provided there was physical space for expansion. Space limitations were removed by the rise of home computers and the invention of the Internet. These allowed annual information growth rates of 30% that raised the total to 180 exabytes by 2006 and to over 1.8 zettabytes by 2011. More recently, the total more than doubled every two years, reaching 18 zettabytes in 2018 and 44 zettabytes in 2020, and expected to become 175 zettabytes by 2025.

The Internet is full of such astounding calculations and dramatic projections[1], which never fail to warn that the total may become even higher, as the population of information users and producers keeps increasing, as well as expanding to cover devices generating and sharing data on the IoT. But even if we ever reach a plateau, as with Moore's "law" with respect to computing capacity[2], we already have an enormous problem in our hands: a huge amount of data to manage. 1.2 exabytes are stored only by the big four (Google, Microsoft, Amazon and Facebook), while other big providers like Dropbox, Barracuda and SugarSync, and less accessible servers in industry and academia probably hold similar amounts.[3]

What makes these numbers even more important is that information is not just stored but, above all, intensively and extensively processed. Already in 2008, Google processed 20 petabytes a day. [4] In many respects, it is less interesting how much data we produce on a daily or annual basis than what we do with these data. Not surprisingly, social media and mobile phones dominate in any account of digital data processing: in 2018, people sent 473,400 tweets, shared 2 million photos on Snapchat and posted 49,380 pictures on Instagram. Google handled 3.5 billion searches a day, while 1.5 billion people (one-fifth of the world's population) were active on Facebook every day.

In 2020, the picture slightly changed as a result of the COVID-19 pandemic: we produced 1.7 MB of data per person per second, with a large share again going into social media, while communication platforms like Zoom and Microsoft Teams, as well online shopping and food ordering, attracted significantly more activity.[5] Anything good or bad happening in the world only increases our dependence on the information and communication possibilities of the Internet, especially now that so many of us can afford utilizing them anytime and anyplace on their smartphones. Consequently, safeguarding information quality, veracity, accessibility and flow already forms a major challenge for both producers and consumers of data.

The situation is further complicated by changing attitudes toward information. Not so long ago, most people were afraid of information overload.[6] Nowadays we have moved to a diametrically different point of view and are quite excited about the potential of big data and related AI approaches. From being a worry, the plethora of information we produce and consume has become an opportunity. At the same time, we are increasingly concerned with data protection and privacy, as amply illustrated by the extent and severity of laws like the General Data Protection Regulation (GDPR) of the European Union (https://gdpr.eu). Attitudes may change further, moreover in unpredictable ways, as suggested by reactions to the Facebook–Cambridge Analytica data breach in 2018 and worries about data collection in relation to COVID-19.

Information And Digitization

It is not accidental that we talk about our era as both the information age and the digital revolution — two characterizations that (not coincidentally) appeared in quick succession. The rapid growth of information production and dissemination, the changes in human behaviours and societal standards or the shift from industrial production to information-based economies would not have been possible without digital technologies. Before the digital revolution, there were technologies for recording and transmitting information but they were not capable of processing information or available to practically all. The information age demands digital technologies, which are consequently present in almost every aspect of daily life, making information processing synonymous with digital devices, from wearables to the cloud. This also means that there is increasingly less that we do with alternative means (e.g. order food by phone rather than through an app), especially since a lot of information is no longer available on analogue media. For example, most encyclopaedias and reference works that used to adorn the bookshelves of homes in the second half of the twentieth century are either no longer available on paper or cannot compete with online sources for actuality, detail and multimedia content. Online video, audio and image sharing platforms have similarly resulted in unprecedented collections that include many digitized analogue media. Despite the frequently low resolution and overall quality of transcribed media, there is no practical alternative to the wealth and accessibility of these platforms.

Related to the dominance of these platforms is that most data transactions take place within specific channels and apps. Nobody publishes on social media in general but specifically on Facebook, Twitter, Instagram, Snapchat, TikTok or whatever happens to be popular with the intended audience at the time. Even though overarching search engines can access most of these data, production, storage and communication are restricted by the often proprietary structure of the hosting environments. As a result, digital information tends to be more fragmented than many assume. Leaving aside the thorny issues of data ownership, protection, rights and privacy, the technical and organizational problems resulting from such restrictions and fragmentation may be beyond the capacities of an individual or even a small firm. Being so dependent on specific digital means for our information needs makes us vulnerable in more respects than we probably imagine and adds to the complexity of information management. It also suggests that privacy is totally lost, as data about user actions and communications are collected by tech companies, whose digital products and services we keep on using because of some huge generic advantages, such as the immense extent and power of crowdsourcing on the Internet.

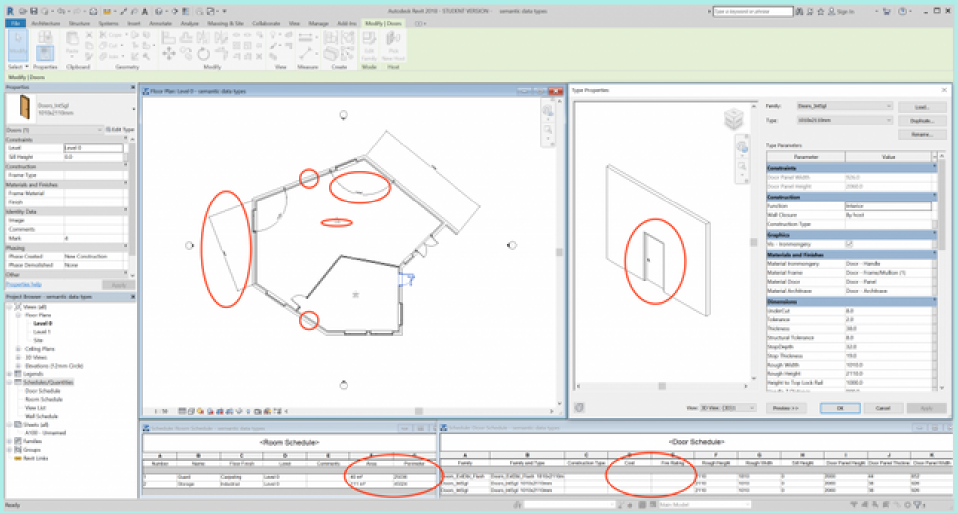
WORKED EXAMPLE

Working with data types in BIM

As we have seen in previous chapters, computerization does not just reproduce analogue building representations. Digital representations may mimic their analogue counterparts in appearance but can be quite different in structure. This becomes evident when we examine the data types they contain. Looking at a BIM editor on a computer screen, one cannot help observing a striking shift in primary and derivative data (Figure 11 & 12): most graphic elements in views like floor plans are derived from properties of symbols. In contrast to analogue drawings, dimension lines and their values in BIM are derivative, pure annotations like floor area calculations in a space. This is understandable: the ease with which one can modify a digital representation renders analogue practices of refraining from applying changes to a drawing meaningless.

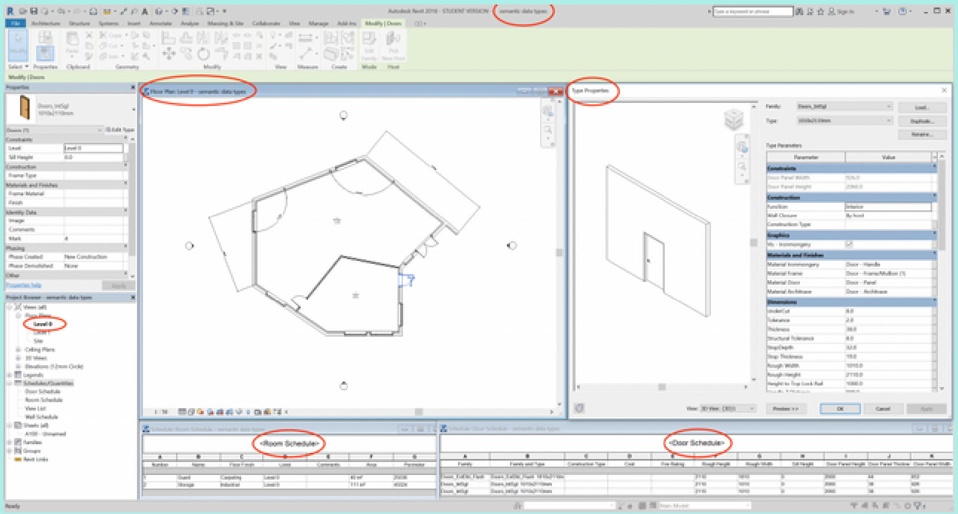
Step 1: First do this

Less intuitive is that even the lines denoting the various materials of a building element are derivative, determined by the type of the symbol: if the type of a wall changes, then all these graphic elements change accordingly. In analogue representations the opposite applies: we infer the wall type from the graphic elements that describe it in terms of layers of materials and other components.



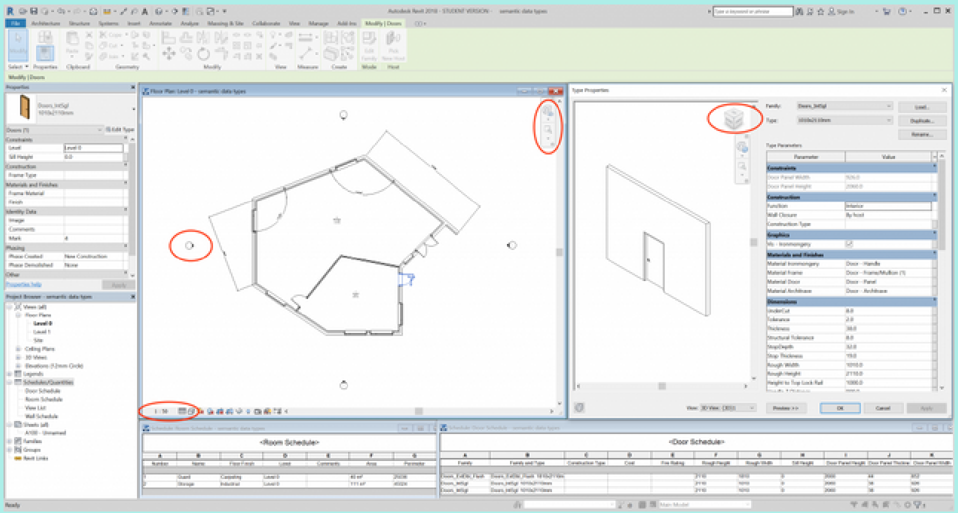
Step 2: Then this second thing

The main exception to this shift is the geometry of symbols. As described in the previous chapter, when one enters e.g. a wall in BIM, the usual workflow is to first choose the type of the wall and then draw its axis in a geometric view like a floor plan. Similarly, modifications to the location or shape of the wall are made by changing the same axis, while other properties, like layer composition and material properties of each layer, can only be changed in the definition of the wall type.



Step 3: Finally this third thing

One can also change the axis by typing new coordinates in some window but in most BIM editors the usual procedure is interactive modification of the drawn axis with a pointer device like a mouse. Consequently, primary data appear dispersed over a number of views and windows, including ones that chiefly contain derivative data.



Most schedules are not necessary for entering entities in a model, in contrast to a window containing the properties of a symbol, from where one chooses the type of the entity to be entered. In managing the primary data of a symbol one should therefore focus on the property window and its contents.

Regardless of such problems, however, it is inevitable that the means of information production, dissemination and management will remain primarily digital, with growing amounts of information available to us and often necessary for our endeavours.

Digitization creates new opportunities for our information needs but, on the other hand, also adds to the problems that must be resolved and their complexity. Digitization is so widely diffuse and pervasive that we are already in a hybrid reality, where the Internet and other digital technologies form permanent layers that mediate even in mundane, everyday activities, such as answering a doorbell. In a growing number of areas, the digital layers are becoming dominant: social media are a primary area for politics, while health and activity are increasingly dependent on self-tracking data and economies are to a large extent about intangible data. Consequently, safety and security in cyberspace are at least as important as in reality. Moreover, they call for dynamic, adaptable solutions that match the fluidity and extent of a digital information infrastructure. It follows that, rather than putting our faith in currently dominant techniques, we need to understand the principles on which solution should be based and devise better approaches for the further development of information infrastructures.

Interestingly, these infrastructures are not always about us. One aspect of the digital complexity that should not be ignored is that a lot of machine-produced data (and hence a lot of computational power) goes into machine-to-machine communication and human-computer interaction, e.g. between different systems in a car (from anti-lock braking systems and touch-activated locks to entertainment and navigation systems) or in the interpretation of user actions on a tablet (distinguishing between pushing a button, selecting a virtual brush, drawing a line with the brush or translating finger pressure into stroke width). Such data, even though essential for the operations of information processing, are largely invisible to the end user and hence easy to ignore if one focuses primarily on the products rather than the whole chain of technologies involved in a task. On the other hand, these chains and the data they produce and consume are a major part of any innovation in digital technologies and their applications: we have already moved on from information-related development to development dependent on digitization.

Effects of digital information

The practical effects of digital information technologies are widely known, frequently experienced and eagerly publicized. Digitization is present in all aspects of daily life, improving access and efficiency but also causing worries for lost skills, invasion of privacy and effects on the environment. With apps replacing even shopping lists, handwriting is practiced less and less, and handwritten text is becoming more and more illegible. Communication with friends, colleagues, banks, authorities etc. is predominantly Internet-based but cannot fully replace physical proximity and contact, as we have seen in the COVID-19 pandemic. Electricity demand keeps rising, both at home or work and for the necessary infrastructure, such as data centres.

Other, equally significant effects, are less frequently discussed, arguably because they go much deeper and affect us so fundamentally that we fail to recognize the changes. For example, with the easy availability and wide accessibility of information, it is becoming increasingly difficult to claim ignorance of anything — much harder than it has been since the newspaper and news agency boom in the second half of the nineteenth century, and the radio and television broadcasting that followed. More and more facts, events and opinions are becoming common knowledge, from what happens today all over the world to new interpretations of the past, including absurd complot theories. As patients, citizens, students, tourists or hobbyists we can no longer afford to miss anything that seems relevant to our situations or activities.

Another cardinal effect is that we are no longer the centre of the information world, the sole or ultimate possessor and processor of information. Our environment has been transformed and enriched with machine-based capacities that rival and sometimes surpass our own, so changing our relation to our environment, too. Interestingly, our reactions to this loss of exclusivity are variable and even ambivalent. On one hand, we worry about the influence of hidden algorithms and AI, and on the other, we are jubilant about the possibilities of human-machine collaboration. Dystopian and utopian scenarios abound, while we become more and more dependent on information-processing machines. One of the key messages of this book is that, regardless of hopes and fears, there are principles on which we can base our symbiosis with these machines: tasks we can safely delegate to computers and support we can expect from them in order to improve our own information processing and decision making.

STUDY TIP

Find videos that expand on the concepts covered in each section. For example, Computational Design in the Making: Trends and Meanings

Finally, the most profound and arguably lasting effect of digitization is that it invites us to interpret and even experience the world as information, understanding practically everything in terms of entities, properties, relations and processes. Our metaphors for the world were always influenced by the structure of our artefacts: the things we had designed and therefore knew intimately. Projecting their functioning and principles to other things we have been trying to comprehend, like the cosmos, made sense and enabled us to develop new knowledge and technologies. Current conceptual models of reality are heavily influenced by digital information and the machines that store and process it. Human memory processes are explained analogically to hard drive operations and our visual perception is understood by reference to digital image capture and recognition. Such conceptual models are a mixed blessing. As explanations of the mind or social patterns they can be reductionist and mechanistic but at the same time they can be useful as bridges to processing related information with computers.

Information management

All the above makes information management (IM) a task that is not exclusive to managers and computer specialists. It involves everyone who disseminates, receives or stores information. Very few people are concerned with IM just for the sake of it. Most approach information and its management in the framework of their own activities, for which information is an essential commodity. This makes IM not an alien, externally imposed obligation but a key aspect of everyone's activities, a fundamental element in communication and collaboration, and a joint responsibility for all — a necessity for anyone who relies on information for their functioning or livelihood.

Given the complexity of our hybrid reality and the lack of transparency in many of our approaches to it, this book bypasses technical solutions and focuses on the conceptual and operational structure of IM: the principles for developing clear and effective approaches. These approaches can lead to better information performance, including through reliable criteria for selecting and evaluating means used for their implementation. In other words, we need a clear understanding of what we have to do and why before deciding on how (which techniques are fitting for our goals and constraints).

BIOGRAPHY

Alexander Koutamanis

Alexander Koutamanis is associate professor of computational design at the Faculty of Architecture & the Built Environment, Delft University of Technology, the Netherlands. He has studied architecture at Aristotle University of Thessaloniki, Greece, and received his PhD from Delft University of Technology on the automated recognition of architectural floor plans.

The book presents a coherent theory of building information, focusing on its representation and management in the digital era. It addresses issues such as the information explosion and the structure of analogue building representations to propose a parsimonious approach to the deployment and utilization of symbolic digital technologies like BIM. It also considers the matching representation of AECO processes in terms of tasks, so as to connect to information processing and support both information management and decision taking.

The proposed principles include definitions of information and representation, and operational structures for connecting process management to IM. IM therefore becomes a matter not of brute force (by computers or humans) but of organization and relevance. One can store all documents and hope for the best but stored information is not necessarily accessible or usable. As we know from searches on the Internet, search machines can be very clever in retrieving what there is out there but this does not necessarily mean that they return the answers we need. If one asks for the specific causes of a fault in a building, it is not enough to receive all documents on the building to browse and interpret. Identifying all information that refers precisely to the relevant parts or aspects of the building depends on how archives and documents have been organized and maintained. To achieve that, we cannot rely on exhaustive, labour-intensive interpretation, indexing and cross-referencing of each part of each document. Instead, we should try to understand the nature and structure of the information these documents contain and then build better representations and management strategies, which not only improve IM but also connect it better to our processes and the tasks they comprise.

KEY TAKE AWAYS

- Digitization has added substantial possibilities to our information-processing capabilities and promoted the accumulation of huge, rapidly growing amounts of information
- Digital information and its processing are already integrated in our everyday activities, rendering them largely hybrid
- We are no longer the exclusive possessor or even the centre of information and its processing: machines play an increasingly important role, including for machine-to-machine and human-to-machine interactions
- Information management is critical for the utilization of digital information; instead of relying on brute-force solutions, we should consider the fundamental principles on which it should be based

EXERCISE

1. Calculate how much data you produce per week, categorized in:
    1. Personal emails
    2. Social media (including instant messaging)
    3. Digital photographs, video and audio for personal use
    4. Study-related emails
    5. Study-related photographs, video and audio
    6. Study-related alphanumeric documents (texts, spreadsheets etc.)
    7. Study-related drawings and diagrams (CAD, BIM, renderings etc.)
    8. Other (please specify)
2. Specify how much of the above data is stored or shared on the Internet and how much remains only on personal storage devices (hard drives, SSD, memory cards etc.)
3. How do the above (data production and storage) compare to worldwide tendencies?

RECOMMENDED FURTHER READING

- Blair, A. et al. (eds.), 2021, *Information: a historical companion.* Princeton: Princeton University Press.
- Graham, M., & Dutton, W.H. (eds.), 2019, *Society and the Internet.* Oxford: Oxford University Press.
- Floridi, L., 2014. *The fourth revolution.* Oxford: Oxford University Press.

NOTES

1. Calculations and projections of information accumulated by human societies can be found in: Rider, F., 1944, The Scholar and the Future of the Research Library. New York: Hadham Press; Lyman, P. & Varian, H.P. 2003, "How much information 2003?" http://groups.ischool.berkeley.edu/archive/how-much-info/; Gantz, J. & Reinsel, D., 2011, "Extracting value from chaos." https://www.emc.com/collateral/analyst-reports/idc-extracting-value-from-chaos-ar.pdf;Turner, V., Reinsel D., Gantz J. F., & Minton S., 2014. "The Digital Universe of Opportunities" https://www.emc.com/leadership/digital-universe/2014iview/digital-universe-of-opportunities-vernon-turner.htm; "Rethink data" Seagate Technology Report, https://www.seagate.com/nl/nl/our-story/rethink-data/

2. Intel co-founder Gordon Moore observed in 1965 that every year twice as many components could fit onto an integrated circuit. In 1975 the pace was adjusted to a doubling every two years. By 2017, however, Moore's "law" no longer applies, as explained in: Simonite, T., 2016. “Moore’s law Is dead. Now what?” Technology Review https://www.technologyreview.com/s/601441/moores-law-is-dead-now-what/

3. Source: https://www.sciencefocus.com/future-technology/how-much-data-is-on-the-internet/

4. The claim was made in a scientific journal paper: Dean, J., & Ghemawat, J., 2008. "MapReduce: simplified data processing on large clusters" Commun. ACM 51, 1 (January 2008), 107–113, https://doi.org/10.1145/1327452.1327492. Regrettably, Google and other tech companies are not in the habit of regularly publishing such calculations.

5. There are several insightful overviews of what happens every minute on the Internet, such as: https://www.visualcapitalist.com/?s=internet+minute; https://www.domo.com/learn/infographic/data-never-sleeps-8; https://www.domo.com/learn/infographic/data-never-sleeps-6

6. The notion of information overload was popularized in: Toffler, A., 1970. Future shock. New York: Random House.

Design sample C

A chapter with content examples for the following:

1. Content opener image
2. Case Study
3. Summary
4. Further reading
5. Sidenote (warning)

The Science of Visuals

If you are new to developing visuals, the creation of a visual will likely take you longer than presenting the same information in a text-based format. In this chapter we present a case for utilising visuals based on cognitive psychology. Hopefully, this encourages you to persist in taking the time to build your skills in creating visuals. The chapter also briefly reviews the archaeological and cultural aspects of visuals to highlight that the creation and interpretation of visuals cannot be separated from the cultural context in which they are used.

2.1 The limited working memory

The reason for using visuals becomes clearer when we understand the architecture of working memory. This section does not provide a comprehensive exploration of working memory (for more information on this, refer to the recommended readings at the end of this chapter), but simply explores how two slave systems within working memory – the phonological loop and visuospatial sketchpad – help explain the beneficial effect of visuals. Further, the concept of cognitive load is introduced and linked to the architecture of the working memory. Through appreciating the issue of limited working memory, the architecture of the working memory, and cognitive load you are better informed to make strategic choices in how you communicate with your stakeholders. These concepts are drawn from both cognitive psychology and instructional design – the design of educational materials.

CASE STUDY

Concept exploration: working memory under load

In 2013, Dr Peter Doolittle used the following exercise to help his TED audience discover the working memory and how it can be maximised.

In summary, first Dr Doolittle asked his audience to remember five words – no writing them down! Then, while remembering the five words, he asked them to undertake a series of tasks that put pressure on the working memory: performing a mathematical calculation and listing the five last letters of the alphabet (backwards)!

Note: As you read further in this chapter you will see that this dual-task exercise is the foundation for many experiments exploring working memory.

Commonly, those who can remember the five words and actually perform the two tasks have maximised their working memory by visualising the five words as an image. This image is held in the visuospatial sketchpad while the other tasks are performed in the phonological loop.

2.2 The architecture of working memory

Working memory is defined by Baddeley et al. (2020) as 'a limited capacity system for the temporary maintenance and processing of information in the support of cognition and action'. The functioning of the working memory remains debated and is acknowledged to be continually evolving. However, the model presented here is that proposed by Baddeley and Hitch, which has broad acceptance and has significant influence in this field (Baddeley et al., 2020). Baddeley and Hitch's model conceptualises working memory as an interface between sensory input and long-term memory (refer to **Figure 3.1**). The working memory holds information that enables a range of cognitive tasks to be performed. The working memory also transfers information into and from the long-term memory. Important to the argument for using visuals in project communications, working memory is limited (Chen & Kalyuga, 2020).

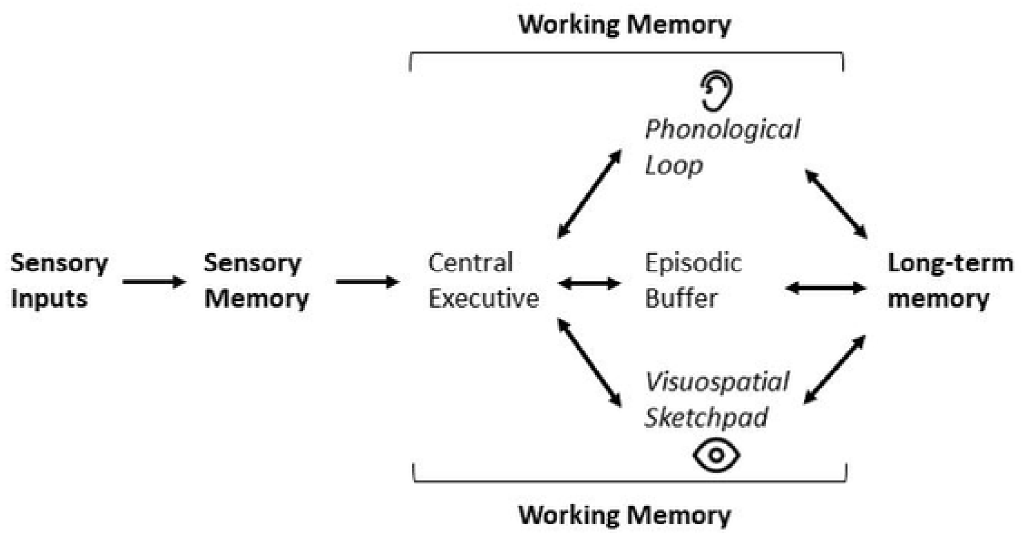


Figure 2.1: Components of the working memory

Components of the working memory include the central executive, phonological loop, and visuospatial sketchpad (Baddeley, 2006). The central executive has limited capacity, is termed as an attentional control system and fulfils a co-ordinating function for the phonological loop and visuospatial sketchpad (Baddeley, 2006; Baddeley et al., 2020). The loop and sketchpad are sometimes labelled as subsidiary slave systems (Baddeley, 2006). The phonological loop holds and rehearses auditory and speech-based information (Baddeley, 2006). Visual information is stored in the visuospat–

ial sketchpad (Baddeley, 2006). Both these slave systems have storage limits and capacity is not transferred across the systems. The episodic buffer is a fourth component of working memory but is less understood (Baddeley, 2006). The cognitive benefits of using visuals are attributed to the two distinct slave systems, and the fact that their capacities are not transferred.

Baddeley and Hitch's working memory arguably aligns with Paivio's dual coding theory (Thomas, 2021). According to the dual coding theory, visual information is more easily remembered than non-visual information in sequential memory tasks (Paivio, 1971). To elaborate using Paivio's early experiments, if a series of words are presented to a person in rapid succession, and then a series of images – *without* time for the person to 'name' the image – the sequence of words are remembered better than the sequence of images (Paivio & Csapo, 1969). However, when presented at such a pace that the person can 'name' the images, their recall of the sequence of images is approximately equal in accuracy to their recall of the sequence of words (Paivio & Csapo, 1971). It is important to highlight that these early experiments were focused on assessing capacity for storing *sequential* information. Paivio and Csapa's (1971) experiments also establish differences in recall depending on whether words refer to concrete objects or abstract concepts. This distinction is relevant to visualisation in project management where concepts being communicated are often abstract. Dual coding theory would espouse that the more 'concrete' the communication, the more likely the message is remembered.

Similar to Baddeley and Hitch's working memory architecture, and helping explain the naming of their theory, according to Clark and Paivio (1991), the human mind has two types of codes (representations): verbal and imagery. According to dual coding theory, retention and retrieval is enhanced when both a verbal and imagery representation is created. That is, the memory is stored in two systems rather than just one. Paivio's theory is associated with the 'pictorial superiority effect' (Yang et al., 2017) and recent studies continue to find that when both images and text are utilised there is an increase in reader engagement (Yang et al., 2017).

WARNING

It is important to caution that while dual coding theory has influenced numerous aspects of psychology research, it is not without controversy, with counter perspectives including the 'propositional' theory and the 'common coding theory'.

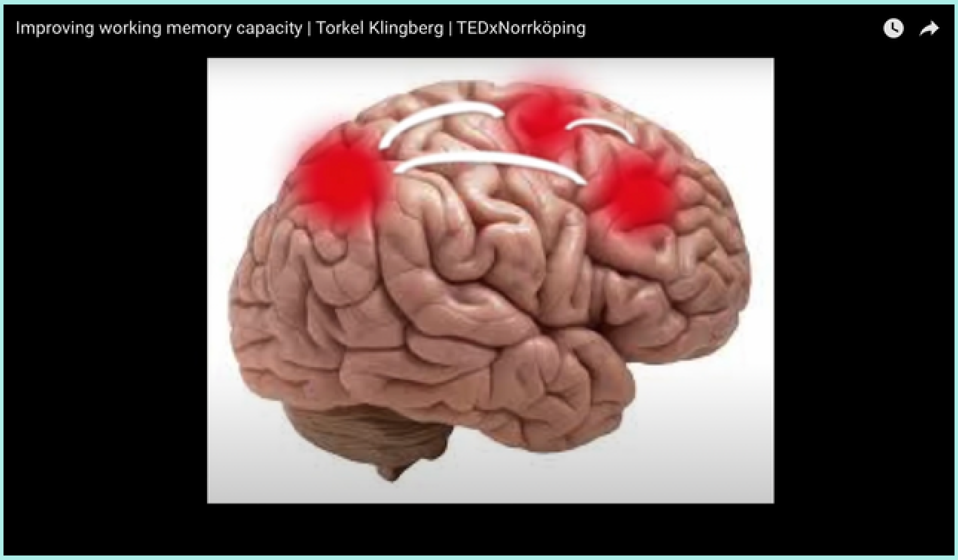
2.3 Working memory and cognitive load

Cognitive load – more simply stated as 'mental effort' – is linked to depleted working memory (Chen & Kalyuga, 2020; Clark et al., 2006). Cognitive load theory has connections to the concept of the magical number of 7+/- 2 (see **Concept Exploration 2.2**) and is associated with John Sweller (Clark et al., 2006). When communicating, it is beneficial to decrease wasteful cognitive load and maximise the capacity of project stakeholders' working memory architecture. As demonstrated in Peter Doolittle's activity (see **Concept exploration 2.1**), a key mechanism for achieving this is through utilising the capacity in both the visuospatial sketchpad and the phonological loop (Clark et al., 2006). The benefits of utilising both systems is established in various studies. For example, if a person is asked to perform a primary task which utilises the phonological loop, and then a secondary task which also utilises the phonological loop, performance is compromised (Clark et al., 2006). However, if the primary task utilises the phonological loop and secondary task utilises the visuospatial sketchpad there is minimal adverse performance impact (Clark et al., 2006).

CASE STUDY

Concept exploration 2.2: limits and potential of working memory

In this short video [approx. 11 mins], Professor of Cognitive Neuroscience, Torkel Klingberg describes the limits of, but also potential to train the working memory. He briefly introduces the tendency to remember 7+/-2 elements**,** but importantly reveals that game-like exercises are being developed to maximise working memory.



Cognitive load theory identifies multiple types of load. It is intrinsic load that is most relevant to the use of visuals. Intrinsic load is associated with the processing that *needs* to occur to achieve the communication goal (Chen & Kalyuga, 2020). However, through the use of visuals along with supporting auditory or textual information it is possible to manage this intrinsic load to maximise stakeholders' limited working memory. Extraneous load is associated with a processing burden that is superfluous to the communication goal (Chen & Kalyuga, 2020). Ideally, the choices made in the design of the visual should minimise extraneous load. Plainly stated, this reminds the project manager not to include information in their visual that does not support the message being communicated or the stakeholders' information needs.

2.4 Applied efficacy for the use of visuals

Chapter 3 explores the use of visuals in project management. However, professions beyond project management are also currently increasing the rate at which visuals are used to enhance performance. For example, in the medical profession, an experiment was undertaken with doctors which compared recall of patient data when it included pictorial and textual information compared to the use of no visuals (Wolch et al., 2017). It is normal for recall of patient data to fall over time. However, this decline was less for the doctors who viewed records with pictorial data. Visual management (VM) is a frequently discussed concept in production management research (Tezel et al., 2016), with foundations in the Toyota Production System (TPS) (Koskela et al., 2018). A component of VM is the use of sensory work aids – often visual in nature – to support the production process and continuous improvement. According to Tezel et al. (2016), VM can support transparency, discipline, continuous improvement, job facilitation, on-the-job training, creating shared ownership, management by facts, simplification and unification.

2.5 A historical and cultural perspective

In this chapter the discussion so far has been dominated by a cognitive psychology perspective of visuals with little reference to the archaeology or cultural aspects of visuals. Briefly, we digress to somewhat address this imbalance. The architecture of working memory that we have described, and facts such as sight being dependent on light and the anatomy of our eyes, are important to our understanding of how visuals work and inform how we develop and use visuals (Janik & Kaner, 2018). However, the way we create and interpret visuals is reflective of our life histories and cultures (Janik & Kaner, 2018). When designing visuals this is an important acknowledgement and necessitates an appreciation of the potential interpretations stakeholders will bring to the visual. As will be discussed in **Chapter 5**, the meaning of colours is not universal: colours can have different meanings for people in different cultures (Aslam, 2006). For example, in Anglo-Saxon and Nordic cultures blue is interpreted as masculine, whereas it is associated with femininity in Germanic cultures. Red is associated with love or happiness in China, but fear, anger and jealousy in Slavic cultures (Aslam, 2006). The language of different nationalities also impacts how colour is classified. In some languages, for example Dani and Bassa, there are only two terms for colour: dark and light (Casaponsa & Athanasopoulos, 2018).

The use of visuals is also linked to broader societal developments such as available tools and technologies. In earlier eras, pictograms and ideograms, such as those associated with the Egyptians, fulfilled a significant role in storytelling (Dewan, 2015). The nature and use of such illustrations was linked to available resources to create these visuals. For example, it is suggested that the colour blue was not used by prehistoric artists because this pigment was not easily available (Janik & Kaner, 2018). In today's society it is the increasing availability of sophisticated software and screens that have advanced the use of visuals in diverse domains (Dewan, 2015). Latour (1986) associates visuals with our increasingly knowledge-based occupations. He argues that it is through what he terms 'inscriptions' that the competition of ideas plays out, and that visuals are a particularly effective form of inscription in this race and become sources of power in our societies. The ability of inscriptions to be mobile – spread/shared between people – scalable and reproducible among other features are central to their power (Latour, 1986). To summarise, when developing visuals and considering their use, we cannot separate them from the micro and macro cultural contexts in which they are used.

2.6 Maximising working memory for project stakeholders

Let's return to our primary focus of this chapter – the cognitive psychology of visuals – and apply the architecture of working memory to the project management context. Frequently, a project manager will need to engage with senior executives or managers who are not familiar with the day-to-day aspects of a project but need to provide approvals or make strategic decisions related to the initiative. In such situations, the project manager will often prepare some form of documentation followed by a verbal briefing in a meeting or phone call. For demonstration purposes, let's explore an example where the project manager's ultimate goal is to derive a decision on a supplier to fulfil a critical project requirement. Let's imagine that we could use two different communication approaches to this situation (refer to Table 2.1).

Approach 1:

The project manager could prepare a memorandum with no visuals that discusses the advantages and disadvantages of the multiple suppliers that are under consideration in a text-only format. There may be an expectation that the senior executive has read this in advance of the meeting and the project manager provides a recap in the meeting while pointing to various sections in the memorandum. At the end of the conversation, the project manager hopes the executive will provide a decision on the preferred supplier.

In this approach both the memorandum and conversation are placing load on the phonological loop, and not taking advantage of the visuospatial sketchpad. The working memory is not maximised.

Approach 2:

By contrast, the project manager could prepare a document that presents the comparison of the advantages and disadvantages of the multiple suppliers in a tabular format that makes identification of the recommended supplier more obvious. Certainly, there may be textual narration to summarise the table and an accompanying discussion, but this approach uses both the phonological loop and the visuospatial sketchpad to maximise working memory. Both systems within the working memory are being utilised.

Table 13.1 Comparison of the two approaches with respect to the working memory slave systems

Approach/element	Utilises Phonological loop	Utilises Visuospatial sketchpad
Approach 1: Memorandum and discussion		
Text-based memorandum	✓	
Discussion	✓	
Approach 1: Memorandum with table and discussion		
Memorandum with table	✓	✓
Discussion	✓	✓

Now let's link these two approaches to cognitive load theory. The project manager's communication goal is to enable a decision on a preferred supplier. The intrinsic load for the executive is associated with making this determination. Through using the table in **Approach 2**, the executive's working memory is maximised and therefore the intrinsic load is reduced. In **Approach 1**, there is potential that the executive tries to create some form of table in his mind's eye (or on paper) to leverage the visuospatial sketchpad, but this is (unnecessarily) increasing the intrinsic load of the task. If the memorandum (or table, or discussion) included information superfluous to the decision at hand, this would be creating extraneous load. And should be avoided.

As is prevalent in psychological theorising, the models and theories presented here continue to be explored and tested, have limits and critiques. Nevertheless, they are presented here as an example of the current arguments for the benefits in utilising visuals.

CHAPTER 2 SUMMARY

Working memory, which is essential for problem solving and decision-making is limited

- Working memory includes two slave systems: the visuospatial sketchpad (which holds visual information) and the phonological loop (which holds auditory and textual information)
- Cognitive load can be reduced by leveraging the limited capacity of *both* the visuospatial sketchpad and phonological loop
- The use, development and interpretation of visuals should take into account the cultural contexts in which they are used
- Project managers, through the strategic use of cognitive psychology insights and cultural norms, can enhance their communication

RECOMMENDED READINGS

On the architecture of working memory

- Baddeley, A., Hitch, G., & Allen, R. (2020). A multicomponent model of working memory. In R. Logie, V. Camos, & N. Cowan (Eds.), *Working memory: The state of the science.* Oxford University Press. https://doi.org/10.1093/oso/9780198842286.003.0002
- Klingberg, T. (2009). *The overflowing brain information overload and the limits of working memory.* Oxford University Press. [Ch. 3 – 6].

Designing communication to reduce cognitive load

- Clark, R. C., Nguyen, F., & Sweller, J. (2006). *Efficiency in learning evidence-based guidelines to manage cognitive load.* Pfeiffer. [Ch. 3].

Archaeology and cultural aspects of visuals

- Aslam, M. M. (2006). Are you selling the right colour? A crosscultural review of colour as a marketing cue. *Journal of Marketing Communications*, 12(1). 15-30. https://doi.org/10.1080/13527260500247827 [Table 1].