1 What is Cognition?

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This chapter presents an overview of the structure of cognition research, including questions, methods, findings, explanations, applications, and real-world implications. The second half of the chapter describes components of research articles in the form of a tutorial to develop skill and familiarity with reading and comprehending primary research in cognition.

0.0.1 Instances of Cognition

What is cognition and how does it work? The book is titled "Instances of Cognition" to orient you to the diversity of ideas, approaches, and multi-faceted interests in this field of research. As a side note, later in the course we will discuss theories of how cognition works that are called "instance theories" (Jamieson et al., 2022, readcube link to read the paper online https://rdcu.be/cGGzW). Despite centuries of research into cognition and the wealth of knowledge generated from that work, there remain many unresolved issues and divergent perspectives that have not yet produced widely accepted answers to fundamental questions about the nature and mechanics of cognition.

The diversity of approaches and perspectives in cognition make it difficult to coherently survey the entire field in a textbook. So, this textbook adopts a museum metaphor to help structure the overview. Consider the task of learning about everything in a museum like the Metropolitan Museum of Art. It's an impossible task. The MET is way too big to see in one day. It has many rooms with countless artifacts, each with their own histories. A tour guide takes you on a path through the museum while providing context and background and highlighting interesting tidbits. However, a comprehensive understanding of the story behind a single artifact could require years or lifetimes of careful investigation.

Cognition is like the museum. It contains many artifacts in the form of questions, methods, findings, theories, applications, and implications for society. This textbook is like a museum tour guide. It is intended to highlight different domains in cognition, and hopefully find ways to tell compelling stories along the way. Like the MET is open to the public, much of the research we will discuss is open to you, in the form of published journal articles and books.

0.0.2 Questions of cognition

Let's address two types of questions: What is cognition? And what kinds of questions do researchers ask and seek answers to about cognition?

0.0.2.1 Defining Cognition

An everyday definition of cognition involves anything to do with how your mind works. We will explore cognition from this everyday perspective, and from more formal perspectives in the cognitive sciences.

Ulric Neisser popularized the term "Cognitive Psychology" in his 1967 textbook by the same name (Neisser, 1967). He defined cognition as:

> "…all processes by which the sensory input is transformed, reduced, elaborated, stored, recovered, and used".

I credit Neisser with coining the term "Cognitive Psychology" in 1967; however, Thomas V. Moore published a lesser known textbook called "Cognitive Psychology" in 1939 (Moore, 1939). Thanks to a twitter thread by Steve Most for pointing this out, and see Surprenant & Neath (1997) for a review of Moore's ideas.

Neisser's definition suggests that cognition encompasses various mental processes that receive, change, interpret, and make sense of the sensory input from the world around us. For example, consider looking at a red gemstone in a jewelry store. Eyes transduce the wavelength of light corresponding to the color red into electrical impulses that spread across massively interconnected groups of neurons in the brain. The sensory input becomes transformed into a visible percept. Further processing may allow identification and recognition of objects within the scene, taking actions like picking up a particular object, or judging aspects of the situation such as whether the gemstone is worth purchasing. Cognitive processing also involves preserving the details of such experiences in memory, which allows previous experiences to be stored, retrieved, and used in the present moment.

Neisser's definition remains current, but is also somewhat limited to a particular information processing view of cognition (discussed in a later chapter). Neisser also expressed a broad outlook on the potential of cognitive research in this critical comment:

> "If X is an interesting or socially important aspect of memory, then psychologists have hardly ever studied X". ("Remembering the Father of Cognitive Psychology," 2012)

Neisser's critique also remains current. Among the rooms of the metaphorical cognitive museum, we will encounter examples of research that Neisser might have criticized for being uninteresting or not socially important. Although significant research has been conducted, various exciting and socially relevant aspects of cognition continue to be understudied. In other words, some rooms in the museum have fewer research artifacts, and there are entire wings that could exist but have not yet been built.

0.0.2.2 Research questions

If you have ever wondered about your mind, then you probably asked a question that cognitive science is interested in answering. Cognitive research can be viewed as a growing list of topics and questions about how cognitive abilities work. To give concrete examples, the next paragraph is a list of questions about cognition.

How do you remember what you ate for breakfast? How do you remember something that happened when you were a kid? How do you learn a language? How do you know how to say a sentence? How do you think your next thought? How do you imagine things? How do you learn new skills, like walking, riding a bike, playing a musical instrument, playing a sport, or a game? How do you learn new information, and how can you study more efficiently? How do you recognize peoples faces? How do you know a tree is a tree and not some other object? How do you make plans for the future? Do you have an inner voice and if so how do you use it? How do you make decisions in your daily life? What makes you prefer some music and not others? How do you control all of your body movements, from moving your fingers to subtle facial expressions? How do you pay attention to some things while ignoring others? Why are some things easy to forget and others hard to forget? How do you learn to read? How do you know the meaning of words? Can you train your brain to get better at something? How many memories can a person have? What does it mean to be smart? Can anyone learn anything to a high degree of skill? How do all of these cognitive abilities develop over the lifespan? How do people understand their own cognition? How do people understand other people's cognition? What about non-human animals, what kind of cognitive abilities do they have?

This was a short list of questions, and there is room for many more. Most of them were *how* questions, and *how* questions are about explaining *how* things work. A goal of posing research questions about cognitive abilities is to produce explanations. An explanation describes how an underlying process or mechanism accomplishes the behavior or ability of interest. The process of generating working explanations involves a research cycle described next.

0.0.3 Methods

This textbook primarily discusses experimental or quasi-experimental research methods used to ask questions about cognition. This section outlines the research cycle and provides examples of common measurement techniques in cognitive research.

0.0.3.1 Research Cycle

The research cycle involves a variety of methods–such as the scientific method– used to generate knowledge about cognition. The research process is represented as a cycle because the outputs of a research project can fuel the inputs of the next project. In general, the process of generating knowledge from a research cycle is incremental and involves many iterations, repetitions, and revisions.

A researcher today might begin with an **observation**–like, some food tastes delicious and other food tastes repulsive…I wonder why…– or, a **question**– like, how can a person learn to read faster? These observations and questions set the general topic for a research project.

Fortunately there is already a large literature on cognition spanning over a hundred years that can be consulted to learn more about the topic. The next step is to review existing findings on the topic that have been published in peer-reviewed scientific journals. This is accomplished by a literature review, which involves obtaining, reading, and critically evaluating primary research articles. Primary research articles are little units of scientific inquiry, each one contains a report about a specific research project. There are several internet search engines to help locate primary research, such as Google Scholar or Semantic Scholar.

Prior research can help you understand the current state of knowledge about a question. For example, if you were interested in the question, "Is it possible to learn how to improve my reading speed?", then, it would be very useful to read the existing literature on this question. One roadblock is that the literature is very large. Finding, reading, and critically evaluating all of the prior research about a particular question is time-consuming. However, engaging in this kind of scholarship is necessary for anyone, especially expert researchers, who intend to understand what is already known about a question before attempting to improve on that knowledge with a subsequent research project.

Even expert researchers may not have enough time to read all of the papers published on their topic of interest. Fortunately,

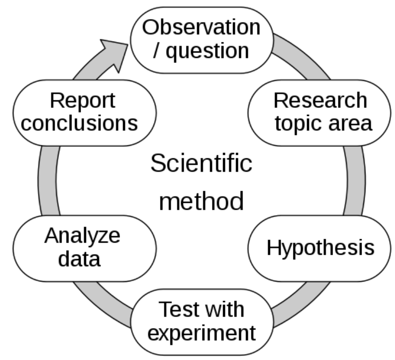

Figure 1: The scientific method illustrated as a research cycle. This section gives a very broad overview of the major components of a research cycle in cognition.

The course website contains a list of academic journals that publish research papers in the field of cognitive psychology.

Although this textbook provides some overview of research and findings in cognition, it is no substitute for learning about cognition by reading original research papers. One of the goals for this course is to help you develop skills to read primary research papers, so that you can more directly appreciate the nature of research claims and findings.

another useful option is to read review articles that summarize a large number of individual research papers on a topic. For example, the review article, “So Much to Read, So Little Time, How Do We Read, and Can Speed Reading Help?” (Rayner et al., 2016) describes numerous findings from the reading literature that are relevant to the question, “How can I learn to read faster?” The reference section of that review paper also lists each of the primary research articles that it discussed, providing another useful way to locate individual research papers. Unfortunately, based on that review paper, there are no known easy methods to dramatically improve reading speed without also sacrificing comprehension (the faster you read, the less you will comprehend).

After a researcher has familiarized themselves with the existing literature, they may come up with new ideas, questions, or **hypotheses**. For example, a general hypothesis could be that vision-based reading speed depends on visual processing speed. Perhaps, factors that make visual processing slow also cause reading speed to be slower, and factors that make visual processing fast cause reading speed to be faster. Ideally, a hypothesis should have testable implications that can be measured by an experiment.

This textbook contains many citations to primary research articles and review articles or books from the cognition literature. Clicking the link should take you to the reference list to get a full citation. Students from Brooklyn College taking this course should have access to all of the papers through the Brooklyn College library. Some papers are behind a pay-wall, but you do not have to pay for them because you can get access through the library. I have all of the papers that I cite, and may be able to provide access through Blackboard. I encourage you to read beyond this textbook and engage yourself with the broader literature to learn more about cognition.

Next, the hypothesis is put to a **test with an experiment**. The purpose of the experiment is to create a controlled situation where specific variables of interest can be manipulated to determine whether they influence the measurements. For example, a researcher might present words in different visual formats that may be processed more quickly or slower by the visual system. For example, **some words could be presented in bold**, and *other words could be presented in italics.* In this case, the manipulated variable is the visual format of the word, which could be bold or italics. The researcher may present words written in both visual formats to participants, and then use an apparatus to measure how long it takes them to read words in each format.

An experiment generates measurements in the form of data that is collected under different experimental conditions. A next stage in the cycle is to **analyze the data**, and determine whether the manipulations had any influences. For example, if visual format reliably influences visual processing and reading speed, then the data may show differences in reading speeds for words presented in bold or italic formats.

The research cycle ideally involves a community of peers, so the final stage of a research project is to **report conclusions**, or otherwise communicate the results of your research. This is typically done by writing up a research report and submitting it for peer-review to a journal. The peer-review process can help identify areas of improvement that the researcher may address in a revision. If the journal accepts the paper, then it becomes a part of the literature on that subject.

The research cycle is a process of figuring out what facts about cognition are real and in need of explanation, and then coming up with theories that explain the facts. The research cycle can be used to test claims, which can lead researchers to discover new facts and create new theories (i.e., a cyclical process). For example, the above researcher might find that presenting words in bold or italics doesn't change reading speed very much. This could inspire another researcher to manipulate the visual form of words in more extreme ways, which could help create new "reading-speed" optimized fonts, or fonts that are "easier" on the eyes, or that help people with dyslexia read more fluently.

Cognition research is also a human activity embedded within a socio-historical context. The discoveries of cognitive research can have applications in society (for better and worse), and the potential prospects of these applications can, in turn, influence the research process by guiding researchers to spend their time on some problems as opposed to others.

0.0.3.2 Experiments and measurements

Cognitive research involves formal experiments and controlled measurements. This textbook assumes you may be unfamiliar with aspects of experimental methods in psychology. Important details of experimental methods will be covered when necessary throughout the textbook.

Experiments are used to manipulate an independent variable and determine whether or not the manipulation influences a dependent variable, or measurement. From our previous example, the experimental manipulation involved presenting words in bold or italics, and the measurement was reading speed. The experimental question was whether or not the type of font would change reading speed. If the experiment is properly controlled and free from confounding variables, then experiments showing positive results suggest a causal connection between the manipulation and the change in the measurement. A positive result means that the manipulation does influence the measurement. For example, if reading speed was found to be faster for bold than italicized words, then the experiment would have shown a positive result of the manipulation. If reading speed was faster for italicized than bold words, this would also be a positive result, because the manipulation still appears to have caused a change in measurement. A null result can also occur, and this happens when the manipulation has no detectable influence on the measurement. For example, a null result would occur when there is no difference in reading speed between bold and italicized words.

There are numerous experimental procedures, manipulations, and measurements specifically designed to answer questions about cognition. In some research domains the objects of inquiry can be measured directly. For example, geologists can measure rock formations, biologists can inspect cells with a microscope, and neuroscientists can measure action potentials of single neurons. In cognition, the objects of inquiry are cognitive processes that are not easy to measure directly. Instead, inferences about cognitive processes are made from measurements of behavior that indirectly relate to a cognitive process of interest.

Consider your ability to form thoughts, and more specifically your ability to generate examples from a category. For example, how many names of mammals can you write down in 5 minutes? If you have time, get out a piece of paper and write down as many names of mammals as you can. Also pay attention to your thought process as you do this.

Your ability to generate mammal names is enabled by cognitive processes involved in language, semantics, categorization, memory, thinking, motor movements, and others, all of which are instantiated in a complex network of physiological processes. As a result, it is incredibly difficult to directly measure all of these processes, even for simple acts of cognition like thinking of an animal name.

Instead, cognitive psychologists use behavioral measures of task performance, that are directly observable, to make inferences about cognition. If you wrote down as many mammal names as you could in 5 minutes, then there are several aspects of your task performance that can be measured. For example, the total number of names written down, the time taken to write each name down, and even patterns like the order and grouping of how the names were written down. These measures of task performance provide clues about how the underlying cognitive processes are working.

In general, measurements in cognition are taken while a participant is performing a task designed by a cognitive psychologist. Measurements are often behavioral aspects of task performance, but may involve measures of physiological processes like heart rate. Common behavioral measurements include accuracy and reaction times to complete actions or portions of a task. Technology like eye-trackers can measure eye-movements during task performance; or systems like the X-box Kinect can be used to measure body motion. People may be asked to make judgments on rating scales and generate or produce information like words or drawings. Common physiological measurements include heart rate, skin-conductance, and pupil-dilation, which sometimes correlates with cognitive activities. Common non-invasive neuro-physiological techniques include EEG, fMRI, MEG, and PET, for measuring correlated brain activity during task performance.

The development of measurement tools can be a creative process. A personal favorite of clever tool development is from Patrick Rabbitt, who was investigating the skill of typewriting on mechanical typewriters (Rabbitt, 1978). He wondered whether typists might hit keys more softly when they make errors, perhaps because they knew they were making an error, and were trying to stop the keystroke before committing the error. The clever bit was how to measure response force without creating a special typewriter capable of measuring forces for individual key-presses. Rabbitt had typists type on layers of carbon paper using a mechanical typewriter. With this apparatus harder keystrokes would impress on deeper layers of the carbon paper, while softer keystrokes would only impress faintly on shallower layers. After a typist finished typing some words, Rabbitt was able to inspect the layers of carbon paper and roughly determine how much force was applied to each keystroke. Rabbitt did find evidence that typists pressed keys more softly when they were making some errors. This is an example of a finding or phenomena which we discuss next.

0.0.4 Findings, effects, and phenomena

The research cycle in cognition has produced numerous findings, effects, and phenomena. A **finding** refers very generally to results from the research cycle. For example, Rabbitt found that typists press keys a little bit more softly for some of the errors that they committed. Another general word for finding is observation, and we could say that Rabbitt observed soft responses during error production in his study. I'll reserve the word **effect** for findings that are the result of an experimental manipulation, especially where the manipulation has an effect on the measurement. Finally, **phenomena** refers to classes of related findings or effects.

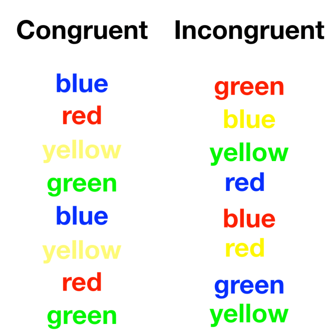

Figure 2: Example Stroop stimuli. Congruent stimuli display the word in a matching ink color. Incongruent stimuli display display the word in a mismatching ink color.

The Stroop effect (Stroop, 1935) provides a useful example. In a Stroop task, subjects are shown stimuli like in the example to the right, and asked to name the ink-color of the stimulus on each trial. For congruent stimuli, the ink-color matches the name of the word, like the word BLUE in the color blue. The correct answer for this stimulus is *blue*. For incongruent stimuli, the ink-color does not match the name of the word, like the word GREEN in the color red. The correct answer for this stimulus is *red*. The typical finding is that participants are faster and more accurate to identify congruent than incongruent stimuli. This difference is termed the Stroop effect [1], which refers to the effect of the congruency manipulation on the reaction time or accuracy measure. Stroop effects can be obtained

[1]named after psychologist J. R. Stroop who invented the procedure

with many different combinations of stimuli that involve manipulations of matching and mismatching target and distractor dimensions, they have been the subject of many investigations, and are collectively referred to as Stroop phenomena [2].

There are too many findings in cognition to discuss in a single book. This textbook aims to give readers a high level overview of many findings and phenomena. Some findings are useful discoveries in their own right that may translate into applications, even without attempts to explain the processes at work. For example, if a researcher found an effect of font size on reading speed, they could use the finding to display fonts in sizes that are optimized for reading quickly. This could be accomplished through trial-and-error, by testing different font sizes and measuring which ones produce the fastest reading speeds. That style of empirical research would not explain why or how font size influences reading speed, and that's OK if the goals of the research were applied in nature.

Other findings are used to make progress in understanding theoretical explanations of cognitive processes. For example, the Stroop effect discussed above may not have obvious applications for the real world. Nevertheless, there have been hundreds of research papers published on the Stroop effect and other cognitive phenomena like it. The purpose of those papers was to test theoretical explanations of the effect. For example, some attention researchers have claimed that the Stroop effect can measure a person's ability to ignore distracting information. From this perspective, understanding manipulations that make the Stroop effect larger or smaller could have implications for understanding how attention works. As we proceed across the chapters, we will examine how experiments are used to evaluate process-based explanations of findings and phenomena.

0.0.5 Explanations, Theories, and Models

There is no single agreed-upon format for theories or models in cognition, so explanations take a variety of formats, from informal verbal theories to formal mathematical models (Guest &

[2] or congruency phenomena, compatibility phenomena, interference phenomena, and cognitive control phenomena

Martin, 2021; van Rooij, 2022). Explanations can also be aimed at different levels of analysis, and they are often metaphorical in nature.

One of the problems with explaining how cognition works is that cognitive systems– like people and animals– are extremely complex and made up of many interacting physical parts. The complexity makes a reductionist account of cognition very challenging, as there are so many parts to explain. For example, a reductionist theory would seek an explanation of phenomena like human memory in terms of the operation of physiological substrates in the brain, which would require an explanation of how neuronal processes work at an electrical and biological level, which would require explanations in terms of physics and chemistry and so on. Physiological accounts of cognitive phenomena are one standard for reductive explanation, but there are others as well.

0.0.5.1 Levels of Analysis

Another approach to explanation in cognition invokes the concept of multiple levels of analysis (Marr, 1982; McClamrock, 1991; Peebles & Cooper, 2015; Pylyshyn, 1984). For example, vision scientist David Marr described three levels of analysis for the task of explaining visual perception from a computational perspective.

Consider first that vision involves a series of transformations beginning at the moment when light hits the retina. From there, photoreceptors in your eyes convert light into electrical impulses sent through the optic nerve, past the optic chiasm, where they are received by neurons in the lateral geniculate nucleus in the thalamus, which is further connected to primary visual areas at the back of the brain. Somehow the visual processing pathways of the brain turn patterns of light falling on the retina into perceptions.

Marr likened visual processing to information processing in a computer system, and suggested that both should be understood in terms of three levels of analysis: computational, representational/algorithmic, and implementational/hardware.

0.0.5.1.1 Computational Level

The computational level refers to the overall goal of a process. For example, what is the purpose of an eyeball? At this level– and in the context of the rest of the visual system– the goal of eyeballs could be to transduce light photons into electrical signals for further processing. At the computational level it is possible for the goal to be realizable in multiple ways. For example, smartphones with digital cameras also have a lens system to convert photons into electrical signals. So, if you were to imagine yourself as an alien researcher wondering about the purposes of eyeballs or digital camera lens, at the computational level they could have the same goal: to capture and convert light for further processing.

0.0.5.1.2 Representational or Algorithmic Level

The representational or algorithmic level refers to how a goal is achieved. Take, for instance, making chocolate chip cookies; the recipe's ingredients and steps are representations and algorithms. Representations are inputs and outputs of the process, such as the raw ingredients that become cookies. The algorithm is a set of instructions for transforming the inputs into the output. A simple recipe for chocolate chips includes a description of the ingredients (representations) and a sequence of steps (algorithm) to process the ingredients into cookies.

To return to the domain of vision, photons are the representational inputs to eyeballs and digital cameras. The algorithm in either system refers to the steps or, the way in which, the inputs are transformed into electrical signals as outputs.

0.0.5.1.3 Hardware implementation level

At the hardware implementation level, we consider how representations and algorithms are physically instantiated and implemented. For instance, what physical elements and processes enable an eye to convert light into electrical signals? Likewise, what physical elements and processes allow a digital camera to capture images and store them in computer memory?

0.0.5.1.4 Summary

This textbook focuses primarily on computational and algorithmic levels of cognitive psychology, according to Marr's levels of analysis. Brooklyn College students taking this introductory course in cognitive psychology may find more in-depth exploration of the brain mechanisms that support cognition in courses such as Mind, Brain and Behavior.

0.0.5.2 Metaphorical Models

Metaphorical models are also used for explanation in cognition. Metaphorical models refer to the process of mapping a simple model system as a metaphor for describing and understanding another more complex system. For example, horse racing has been used as a model for explaining the Stroop effect. The metaphor does not assume that people have horses or a racetrack in their brains. Instead, the metaphor provides terms and functional relationships that can provide well-fitting descriptions of Stroop phenomena and even make predictions about what might happen to the effect under different experimental manipulations.

In a horse race, horses are lined up and wait for the starting signal before running down a track, with the first horse to reach the finish line declared the winner. This process is compared to the Stroop effect, in which a stimulus displaying a word and color is shown on the screen. As the two sources of information – useful for naming the word and the color – race to the finish line, the first to reach will be used to produce the naming response.

Importantly, word-naming is known to be faster than color-naming. In the metaphor, visual information for word recognition is a "faster horse" that gets to the finish line before color information. This metaphor provides language to describe why people might be faster to name the color of congruent than incongruent items. For example, when people respond quickly to the word "BLUE" in blue ink, they may produce the name of whichever information that arrives first. In this case, they would be able to say "blue" even before they finish processing the actual color of stimulus. For an incongruent item, like the word “RED” in green ink, a person should be able to say “red” before they can name the color information “green”.

The horse race metaphor provides a starting point for describing stimulus identification processes and considering potential hypotheses that may explain performance in the Stroop task. For example, following the logic of the above metaphor, people may be fast to name the color of congruent items because they are actually naming the word information, which is processed quickly, instead of the color information. Similarly, people may be slow to name the color of incongruent items because here they must name the color information, which takes longer to process, in order to give an accurate response.

The act of applying the horse race metaphor to the Stroop task may seem a bit silly, as the Stroop task does not involve literal horses. However, borrowing terms and functions from a metaphorical standpoint can help researchers generate new questions to better their understanding. For example, according to the metaphor above, people may be naming the word information on congruent trials, even though they are being instructed to name the color information. It is difficult to determine if people are doing this because their response would be the same if they were naming either the word or the color (e.g. BLUE in blue; the answer is blue for both). This metaphor implies that people may be inadvertently word-naming, prompting a more specific inquiry: are people doing this and, if so, how can it be determined?

If it was possible to confirm the hypothesis that people are inadvertently naming the word instead of the color on congruent trials, then the horse-race metaphor could be further considered. However, evidence to suggest this is not the case also has implications; the validity of the model as written would be put into question, opening up alternative theories to explore. For example, when words match colors, it is possible that the word information helps speed up the process of color identification. This hypothetical facilitation process could explain why people are faster on congruent trials. This example serves to highlight how metaphors can be useful in forming hypotheses which can then be tested with carefully designed experiments to produce evidence for or against the hypotheses.

0.0.6 Applications

To simplify the preceding discussion, the research cycle in cognition produces theory and phenomena that can lead to new applications and technology in the real world. For example, theory about how people learn skills can be used to modify training curricula and enhance the skill-learning process. Similarly, theory and findings about skills like reading explain why there are no easy shortcuts to learn to read faster. Many applications have been derived from individual domains in cognition, and these will be highlighted in the upcoming chapters.

0.0.7 Implications

Cognitive research has spanned a few centuries and has produced many theories, findings, and applications. However, not all implications have been uniformly positive for society, and some applications have negatively impacted certain groups of people (Prather et al., 2022). In light of this, the textbook will periodically discuss socio-historical contexts surrounding the research and researchers that are discussed. To exemplify, we will analyze how research on mental imagery ability and the early development of intelligence testing were impacted by the prevalent eugenics movement of the time. This era of psychology left a profound mark on subsequent cognitive research, raising essential questions about how psychological research should be applied in society.

0.0.8 Trust and Reproducibility

An overarching goal of the research cycle in the cognitive sciences is to create trustworthy knowledge about cognitive processes and abilities. There are multiple paths to creating knowledge that can be trusted, and the research cycle, along with experimental methods, is a common way to achieve good results. However, there are pitfalls to be aware of, and even the most rigorous experimental methods require critical evaluation.

What do I mean by trustworthy knowledge? My standard is that the general public should be able to trust claims that come from research published in the cognitive sciences. For example, if a research paper makes a claim about cognition, the evidence from the paper should be strong enough to support the claim. It would be great if everyone could trust all the results from all published papers in psychology; however, there are several reasons why consumers of research findings should take a critical stance. Taking a critical stance means evaluating the details of the research oneself to determine whether the claims are supported by the evidence. Taking a critical stance is a skill that can be developed with practice.

There are many reasons to take a critical stance when evaluating research, and a major one is lack of reproducibility. Not all the findings in cognition, psychology, or other fields are reproducible. A finding is reproducible when another researcher can repeat an experiment and find the same pattern of results as the original researcher.

On the one hand, I can personally attest to the fact that many findings in cognitive psychology are reproducible and can be trusted and accepted as facts. I have been able to reproduce findings from other labs myself. As a quick example, there are hundreds of papers from multiple labs showing the Stroop effect in various contexts. This provides an overwhelming amount of evidence that the Stroop effect exists.

On the other hand, there are also more than a few examples of findings that have been published in scientific journals that turn out not to be reproducible. For example, through a large collective effort, several labs around the world attempted to replicate findings from 100 different psychology papers, including many from the cognitive sciences (Collaboration, 2015). They found that 97% of the original studies reported positive results; however, looking at the results from the labs that attempted to reproduce the findings, only 36% showed positive results. Most of the original results could not be reproduced! This attempt to estimate the reproducibility of studies in psychology raised several questions, and addressing reproducibility issues continues to be a major concern for psychology.

One question is whether researchers can trust findings published in the literature. If the findings cannot be reproduced, then they may be spurious and should be disregarded. Theories that were attempting to explain spurious findings would need to be updated. Another question is whether the research teams simply failed to reproduce all of the steps from the original experiment. Maybe the finding would be reproducible if the experiment was done correctly. If another research team cannot follow the steps, then researchers should adopt higher standards for communicating their methods, so that others can follow the instructions. In rare cases, some findings cannot be reproduced because of fraud, such as a researcher publishing a paper with fabricated data.

The bottom line here is to be critical in your consumption of information. Although cognitive science as a discipline has very high standards for producing knowledge, individual papers may not meet these standards. Individual findings and claims need to be scrutinized and evaluated, even after they are published in scientific journals. So, don't believe everything you read, even in a published journal article, and be prepared to critically evaluate whether the provided evidence can support the claims being made.

0.0.9 General questions to keep in mind as you learn about cognition

What are the goals of the cognitive sciences and research in cognitive psychology? Who has been involved in setting those goals? Are the goals useful? What kind of questions about cognition have already been asked by researchers? What were the scientific as well as social-historical reasons for why those researchers asked those questions? What answers were found, and how were they informative or not informative about how cognition works? How do the measurements and tools that researchers use to ask questions influence the kind of picture they build about how cognition works? What kinds of questions about cognition are not being asked that should be asked? Why are they not being asked? What benefits to society have been produced by the cognitive sciences? Have the benefits been spread equitably across different groups of people? What costs to society have been produced by the cognitive sciences? How are the costs shared by society? Are there injustices resulting from cognitive science research? Have they been adequately addressed? How should society decide whether or not to proceed with different kinds of research?

0.0.10 Reading primary research articles

Researchers produce knowledge about cognition using the research cycle and communicate their findings in the form of primary research articles, usually published in academic journals. There are many academic journals in the domain of cognition and a list of journals can be found on the course website.

Learning how to read, comprehend, and critically evaluate primary research articles are important skills in general, and essential for engaging with the literature on cognition. There will be opportunities to read primary research throughout the course. This section provides a tutorial on how to read research articles using the QALMRI technique [3].

Here are some reasons why it is useful to improve your ability to read primary research articles.

1. Learn how to find and evaluate scientific research conducted on topics of interest to you. Assess the claims and evidence for yourself to make informed decisions.
2. Evaluate whether the claims made by the media and scientific communities regarding new research findings are trustworthy. Consider the evidence and data to make an informed decision on if the claims should be believed.
3. Look at the evidence to see whether it actually provides an answer to the question that was being asked
4. Examine the questions to determine if they are effective, and understand how to formulate better ones.
5. Understand how theories and hypotheses function in order to make predictions about psychological phenomena.

[3] Adapted from Kosslyn, S. M., & Rosenberg, R. S. (2001). Psychology: The Brain, The Person, The World. Boston: Allyn & Bacon

0.0.11 The QALMRI Method

QALMRI is an acronym for critical parts of research articles. It stands for Question, Alternatives, Logic, Method, Results, and Inference. This section demonstrates using QALMRI as a guide for reading a primary research article. QALMRI can also be used as an activity or assignment, and an example of a QALMRI assignment is given at the end.

0.0.11.1 Step one, find a paper

The first step is to find a primary research article to read. To demonstrate QALMRI, I chose a paper from my own research. The article is titled, "Warning: this keyboard will deconstruct – The role of the keyboard in skilled typewriting" (Crump & Logan, 2010). This paper was published in the journal Psychonomic Bulletin and Review in 2010 and can be freely downloaded as a pdf here.

Before continuing, I suggest you download the paper and give it a quick glance. It it is only 5 pages long.

0.0.11.2 Anatomy of a primary research article

The paper you just downloaded is an example of a primary research article. The components of a research article are very similar; for instance, this one has a title, an abstract, an introduction, methods and results sections for two experiments, a general discussion, and references. Most research papers have similar components.

Research papers are often written with a technical audience in mind—that is, other researchers who are already familiar with the field. As a result, students can find it difficult to identify and comprehend the major points made in a research article. To help with this, we use QALMRI to better understand the components of a research paper.

0.0.11.3 Q stands for Question

Researchers ask and answer research questions. So, your first task is to identify what questions are being asked in the research article. Research questions are usually stated in the abstract or the introduction, and sometimes they are restated near the beginning of the general discussion.

You may notice many different kinds of questions being stated in a research paper. It is helpful to distinguish between **broad questions** and **specific questions**. A single research paper is rarely capable of answering very broad questions, but it may be able to answer a specific question.

The paper you downloaded is about cognitive abilities mediating skilled typewriting on a computer keyboard. This topic is associated with many broad questions, such as: how do people control their own body movements? How do people learn to type without thinking about what their fingers are doing? How do people learn skills? How do people learn language? All of these questions are too large for a single research paper to answer.

The paper also asks a specific question about how the tactile feedback of a keyboard affects typing performance. Specifically, it examines the difference between typing on a keyboard with keys and typing on other surfaces, like a flat surface without keys. What effect does the feeling of the keyboard have on typing performance?

0.0.11.4 A stands for Alternatives

When reading an experimental research paper on cognition, it is important to be able to identify the alternative explanations or hypotheses discussed in the document. It is possible that only one hypothesis is presented, while in other cases a paper may discuss multiple potential explanations. Either way, the hypothesis or alternative should be sufficiently detailed to draw an implication that can be tested by an experiment.

The example paper has two major alternatives about how people are able to move their fingers to individual keys very quickly and accurately, even without looking at the keyboard.

One possibility is that people have an internal cognitive map of the keyboard. The cognitive map represents the location of the keys on a computer, and typists may use this internal "mind" map to direct their fingers to appropriate locations while typing. An implication of the cognitive map idea is that typists may not need to rely on the feeling or tactile sensations of a keyboard in order to type quickly and accurately. Instead, their fingers can move to each key based entirely on directions from this internal map.

An alternative possibility is that people may not rely on an internal map of the keyboard but rather learn associations between the finger movements required for each keystroke and the tactile, haptic, and proprioceptive feedback the keyboard provides. This implies that feeling the keyboard may play a pivotal role in mastering typing, particularly for those who learned to type on keyboards with physical keys.

0.0.11.5 L stands for Logic

The logic of the alternatives or hypotheses is nearly identical to the hypotheses themselves, but more formally stated in terms of if/then statements. Here are two examples of logic statements for each of the alternatives discussed above:

IF typists use an internal cognitive map that does not require feedback from the keyboard to guide their fingers, THEN typing performance should not be influenced by manipulations that remove tactile feedback, such as typing on keys versus a flat surface.

IF typists use feedback from the keyboard to guide their fingers, THEN typing performance should be influenced by manipulations that remove tactile feedback, such as typing on keys versus a flat surface.

0.0.11.6 M stands for Method

The method refers to the tools used to answer the research questions. More specifically, the method is usually carefully designed to test the logical implications of alternative explanations. In experimental research, the method involves at least one independent variable or manipulation, and at least one dependent variable or measurement.

In our example, the method involved having skilled typists copy text while typing on keyboards with different surfaces that provided less and less tactile feedback. The primary manipulation had four levels and involved changing the feeling of the keyboard: a regular keyboard, a rubber button keyboard, a flat surface keyboard, and a laser projection keyboard. Measurements of typing performance (keystroke typing times and accuracy) were collected for each typist as they typed words on each keyboard.

0.0.11.7 R stands for Results

The results are a final product of the research cycle. A given research article may present many results, depending on the complexity of the method. In general, the results refer to an analysis of whether the experimental manipulation impacted the measurements.

In our example, typing performance was measured for four different keyboards. Results were reported in a graph, showing various measures of typing performance, such as reaction time (time to start typing a word), inter-keystroke interval (time between keystrokes), and error rate. The major result was that keyboard manipulation had a significant effect on typing performance. Typists were fastest and most accurate with a regular keyboard, and slower and less accurate on keyboards with less tactile feedback.

0.0.11.8 I stands for Inferences

Inference may be the most important product of a research project. Inferences connect the results back to the original research questions. So, what inferences about the alternative explanations under investigation can we draw based on the results of the research? Inferences are possible if the methods do a good job of testing the logic of the alternatives.

In our example, the logic of the internal keyboard map idea suggested that manipulations to the feeling of the keyboard should not affect typing performance. However, the results of the study showed that reducing tactile feedback from the keyboard causes slower and more error-prone typing. Thus, one inference from the study could be that typists do not rely on an internal map of the keyboard.

0.0.12 Writing a QALMRI assignment

Writing a QALMRI for any research paper (one that you are writing, or one that you are reading) involves writing short answers to each of the QALMRI points using clear and concise language. It is a condensed, short-form version of the research. Your task is to answer these questions:

- Question: What was the broad question? What was the specific question?
- Alternative hypotheses: What were the hypotheses?
- Logic: If hypothesis 1 was true, what was the predicted outcome? What was the predicted outcome if hypothesis 2 was true?
- Method: What was the experimental design?
- Results: What was the pattern of data?
- Inferences: What can be concluded about the hypotheses based on the data? What can be concluded about the specific and broad question? What are the next steps?

0.0.13 Example QALMRI

Even if you haven't read the article, reading a QALMRI should provide you with enough information to get a basic idea of what the article was about. The following QALMRI summarizes our example article by Crump & Logan (2010) (Crump & Logan, 2010).

0.0.13.1 What was the broad and specific question?

The broad questions are about spatial cognition. How do people understand and represent the spatial relationships between objects in the environment? Do people have "spatial maps" in their head?

The specific question is how do typists know where the keys are on the QWERTY keyboard?

0.0.13.2 What are the alternatives?

1. Typists have an internal cognitive spatial map of the keyboard that they use to guide their fingers during typing
2. Typists do not have a map-like representation, instead they rely on learned associations between cues such as the feel of the keyboard to guide their fingers during typing

0.0.13.3 What is the logic?

1. If typists have an internal map of the keyboard, then they should be able to guide their fingers to correct locations based on the map alone and no feedback from the environment. For example, if we could measure "air-typing" without a keyboard, then typists should still be able to put their fingers in the correct locations even when the keyboard is missing because they are relying on their internal map.
2. If typists do not use an internal map of the keyboard, then their finger movements should become slow and inaccurate when they try to type without a keyboard, or in other conditions that change the normal feel of the keyboard, and thereby remove the cues that typists use to direct their fingers.

0.0.13.4 What is the Method?

Typists copied paragraphs in four conditions that manipulated tactile (touching) feedback from the keyboard. They typed on a normal keyboard, a keyboard with the keys removed exposing the rubber buttons underneath, a flat circuit board without, and on a flat table with a laser projection keyboard.

0.0.13.5 Results

Typists were fast and accurate in the normal keyboard condition. Typists were slow and inaccurate in all of the other keyboard conditions, where normal tactile feedback was removed.

0.0.13.6 Inference

The results are *not consistent* with the internal map hypothesis. If typists had an internal map, and did not rely on tactile cues, then they should have typed normally even when the cues were removed. The results are consistent with learned association hypothesis, that typists rely on cues, like the feel of the keyboard, that are associated with particular key locations.

0.0.14 Appendix

0.0.14.1 Glossary

0.0.14.1.1 * Cognition

This textbook defines cognition as processes of mind and behavior, including human and non-human animal minds, and potentially computational minds. Examples of cognitive abilities include perceiving, attending, remembering, thinking, empathizing, deciding, predicting, judging, etc.

- Anything to do with how minds work

0.0.14.1.2 * Dependent Variable

The measurement in an experiment. For example, in a recall memory experiment a researcher could measure memory performance by counting how many words were remembered under different experimental conditions.

0.0.14.1.3 * Independent Variable

An experimental manipulation involving at least two levels. For example, an experiment testing the efficacy of a drug could have an experimental level where participants receive the drug, and a control level where participants do not receive the drug.

0.0.14.1.4 * QALMRI

An acronym used an aid for reading primary research articles. QALMRI stands for Question, Alternatives, Logic, Methods, Results, and Inference. Research papers ask questions about how phenomena work, they propose alternative working explanations, and test the logical implications of those explanations with methods. The methods produce results that can be used to generate inferences about the working hypotheses and generate insight into the phenomena under investigation.

0.0.14.1.5 * Scientific Method

A systematic process using controlled experiments and observation to generate knowledge about phenomena under investigation.

0.0.14.2 * References

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