

IX. Critical Thinking

In education, you often hear of the need to teach “critical thinking.” It seems strange to say that we even *can* teach someone to think, not even to mention the critical part. Isn’t thinking something we do naturally, without thinking? Yes and no. I’m sure you can recall a time that you faced a thorny problem and, through conscious deliberation, managed to solve the problem, thereby gaining a feeling of satisfaction and accomplishment. I’m sure you can also recall a time that you faced a thorny problem and charged right into it without a thought. Perhaps you got lucky and reached a resolution, most likely the result did not lead to a satisfying feeling.

If we can define critical thinking, we can get to the difference between “conscious deliberation” and “charging right in.” (BTW, can you develop scenarios where it might be best to charge right in?)

MACC is not the first institution to try to define critical thinking. There are numerous definitions available. I’ll provide a few here to give you an idea of the variety:

We understand critical thinking to be purposeful, self-regulatory judgment which results in interpretation, analysis, evaluation, and inference, as well as explanation of the evidential, conceptual, methodological, criteriological, or contextual considerations upon which that judgment is based. CT is essential as a tool of inquiry...While not synonymous with good thinking, CT is a pervasive and self-rectifying human phenomenon. The ideal critical thinker is habitually inquisitive, well-informed, trustful of reason, open-minded, flexible, fair minded in evaluation, honest in facing personal biases, prudent in making judgments, willing to reconsider, clear about issues, orderly in complex matters, diligent in seeking relevant information, reasonable in the selection of criteria focused in inquiry, and persistent in seeking results which are as precise as the subject and the circumstances of inquiry permit. Thus, educating good critical thinkers means working toward this ideal. It combines developing CT skills with nurturing those dispositions which consistently yield useful insights and which are the basis of a rational and democratic society.

from: Complete American Philosophical Association Delphi Research Report

Critical thinking is the intellectually disciplined process of actively and skillfully conceptualizing, applying, analyzing, synthesizing, and/or evaluating information gathered from, or generated by, observation, experience, reflection, reasoning, or communication, as a guide to belief and action. In its exemplary form, it is based on universal intellectual values that transcend subject matter divisions: clarity, accuracy, precision, consistency, relevance, sound evidence, good reasons, depth, breadth, and fairness.

National Council for Excellence in Critical Thinking Instruction

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Critical thinking is a habit of mind characterized by the comprehensive exploration of issues, ideas, artifacts, and events before accepting or formulating an opinion or conclusion.

Association of American Colleges and Universities

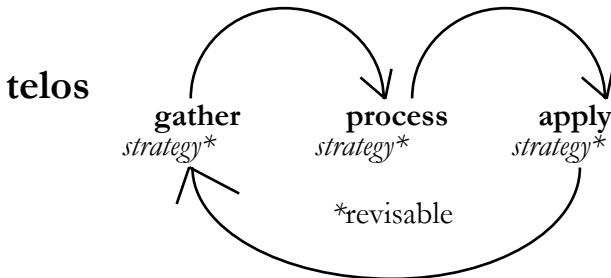
Critical thinking is that mode of thinking--about any subject, content, or problem--in which the thinker improves the quality of his or her thinking by skillfully taking charge of the structures inherent in thinking and imposing intellectual standards upon them.

Elder & Paul

Fair enough; it is a difficult concept to define. Can we cut through the bureaucratic mumbo-jumbo and develop a definition that is easy to understand, visualize, and use? I think so.

The first thing to note, and all these definitions imply it, is that critical thinking is a **behavior**. It is a way of acting—a way that you consciously act on your mind. It is a behavior that, with practice, becomes **habitual** and can be applied to a variety of problems in a wide range of subjects and situations. And, as with writing and reading, the behavior begins with a **telos**, or purpose. What is the reason you direct your mind to critically think? We'll start answering these questions with a graphic of critical thinking developed for this handbook. We'll describe each part and provide some case studies of how critical thinking is **enacted**.

A. An Overview



Critical thinking is a behavior engaged by a telos where the thinker uses revisable strategies to gather and process information, then applies the results to fulfill the telos.

Most likely, you engage in critical thinking without knowing it. Let's say that your dishwasher becomes unmoored from your counter and when you open the door, it tips forward, spilling dishes and silverware on the floor. You pick up the dishes and look underneath the counter and discover two small tabs with holes in them for screws used, you presume, to attach the dishwasher to the counter.

Aha. There are no screws there. So you go to your garage and get two wood screws (not sheet metals screws, nails, or bolts). They both fit easily into the pre-drilled holes in the counter. Not good. So you return and get two thicker screws. You try screwing them in but the screwdriver's head is too small. You get a bigger screwdriver; screw the screws in, and there you go, you have secured the dishwasher using critical thinking.

What began this process? We use the classical Greek word—**telos**—to describe what engages the process. **Telos** means the end, purpose, or goal. In the case above, the telos was to fix the dishwasher. In all cases, critical thinking is engaged when you lack what you need to fulfill your telos. In most cases, critical thinking gathers information to solve a problem. As anyone who has lived in this complex world knows, problems come in all shapes and sizes.

Sometimes those problems are given to you in your college courses:

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So here for X

What are three causes of the War of 1812?

What happens to demand for a product when its price rises?

What is the ideal ph level for this specific organism to thrive?

How do you find a short in a complicated circuit?

If you drop a ball from 300 feet, how long will it take for it to hit the ground?

How do you program a self-replicating system?

Sometimes those problems are moral:

A friend asks you to lie for him, should you?

You're "kind of" seeing someone, and someone you like asks you out, is it ok to go?

You need your job to support your sick child and discover your employer is engaged in illegal, but not very damaging, activity, should you report her?

You witness a friend cheating on their spouse? Should you tell the spouse?

You find \$10,000 in cash in a field while hiking, what should you do with the money?

Sometimes those problems appear when considering larger issues in your life:

How do you maximize your potential as a student?

What career should you choose?

Should you remain with your church, find a new one, or stop attending entirely?

What's the best way to stay fit given your schedule?

What kind of car should you buy?

Is it time to get married?

We can generate an endless number of problems. Each class you take in college can generate an endless number of problems. Each stage of your life can generate an endless number of problems.

What characteristics do these problems share? Each requires purposeful action. Each requires that the person **gather** information, **process** that information, and then **apply** the result of the process to the problem. Each problem requires the behavior of critical thinking. Even if critical thinking is engaged in speculation, the critical thinker speculates because she doesn't know what she wants to know—she uses critical thinking to expand her knowledge.

Critical thinking requires a **strategy** at each stage. It is common sense that you should only gather information that pertains to the problem at hand. You should only use a process or processes that operate effectively on what you've gathered, and, of course, you need to apply the results to the appropriate problem. You wouldn't want your doctor to put a cast on your right arm if the diagnosis is that the left arm is broken.

A strategy is a reason-based and deliberate method to achieve your telos. One of the goals of this handbook is to survey a range of strategies that work in critical thinking situations. Ideally, you want your strategy to accomplish the

most for the least amount of energy—it is in the nature of critical thinking to be seeking efficiencies at every stage. *Did you hear the one about four engineers who spent 10 hours figuring out how to cut 10 minutes out of a 20 minute task?* Our engineering friends know all about strategy. Strategy is **revisable**. You should be constantly improving your strategy. Indeed, that is the “critical” part of critical thinking. You are not only trying to solve a problem when you critically think, you are trying to figure out the most efficient and effective way to solve it. If your efforts do not result in a solution, you need to figure out how to fix your strategy so that it does.

B. Recursivity

You revise strategy because you cannot achieve your telos until you get the right kind of information, the right kind of process and the right kind of application. This highlights another aspect of critical thinking—it is a **recursive** process, not a **linear** process. A linear process is like climbing stairs—first step, second step, third step, and so on until you reach your destination. A **recursive** process is a process that engages subroutines. For example—take the first step, if you land with your right foot take two steps down, if you land with your left foot, take two steps up, then proceed to the next step. Nested inside the main process are other processes.

We talked about recursive processes when discussing writing—the same idea applies to critical thinking (indeed, you may noticed that reading, writing, and critical thinking share many of the same cognitive features). You may have to gather (revise strategy), gather (revise strategy), gather (revise strategy), before you can move on to the process stage where you may have to revise your strategy again—that is the nature of recursive processes. The clever student might argue that you are using the entire process of critical thinking when you choose how to revise your strategy. Yes. That’s the nature of recursive processes: the big process is made up of a number of smaller processes that may look like the big process.

C. The Gathering Stage

All gathering involves sensory activity at some point, but observation is not always the origin of gathering. For example, you will be asked in a number of classes to write research papers. In that case, the gathering will be collecting sources to use in your essay (of course you’ll have to use your eyes to read what

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those sources have to say). For scientists, a well-thought out experiment gathers significant results that can then be passed over to the processing stage. For an economist, gathering may mean searching datasets of economic activity. For a sociologist it may be designing, handing out, and collecting surveys. For a mathematician gathering may mean looking at a set of problems to learn what rule governs that set.

You need a strategy for gathering information because you need the right kind of information. For example, while collecting sources for your research paper, you'll need those sources to be unbiased. The scientist's experiment will need to follow the protocols for experimentation, as will the design of the sociologist's survey. The mathematician's problem set needs to be consistent and the economist's dataset up to date.

Let's think about gathering in the dishwasher problem. First you had to discover what was wrong. You did this through observing how the dishwasher should be attached to the counter. But why didn't you start by looking at the bottom of the dishwasher? Or under the sink? Because you wanted to maximize the amount of pertinent information you receive from your observation, so you started looking at a natural place to attach the dishwasher to the counter. That was your strategy. In order to maximize the efficiency of gathering, you need to figure out what you need to look for, and how to look for it, before you start looking.

Imagine you're in a child development class which requires you to spend time in a daycare center. Your assignment is to write a report, based on your observations, on how 3-4 year olds interact with each other. What will be your strategy? First, you'll want to set yourself up in the room where 3-4 year olds play. Second, you'll need to be there when they interact. Third, you'll need to figure out where to position yourself to observe the fullest range of interaction. Fourth, you'll want to either videotape their interactions or take notes. When you have decided on each of those issues (your strategy) you'll be ready to observe (gather).

Maybe the first day of observation you discover that the children keep coming up to you to look at the camera you are recording them with and they interact with you more than they interact with each other. So the next time you observe, you take notes instead of videotaping—you revise your gathering strategy.

1. Objectivity

In the section on writing we discussed the necessity of being objective when engaging in certain kinds of rhetorical situations. Gathering without bias (as well

as gathering unbiased information) is essential to critical thinking. If you gather information that supports what you already know, you won't ever learn anything.

Let's think about the situation described above. Maybe when you were four years old you were bullied by a blond-haired boy and there is a blond-haired boy in the playroom you are to observe. Will you watch him like a hawk to observe his bullying behavior? If you did, you wouldn't be objective and, no matter how effectively you process and apply your observations, your project will be flawed because of your bias against blond-haired four year olds. *Bias in/bias out.*

It takes a certain kind of rigor to observe objectively. First, that rigor is sensory. It requires careful attention. Observation cannot be one part of a "multi-task." It is only effective if it is a "uni-task"—the sole object of your energy and focus.

Second, that rigor is, I would argue, *moral*. You have to remove your self, your ego, from the object of your observation. This is no easy task, particularly in a culture that encourages us to share how things affect us, not how they are in themselves.

I observe this phenomenon in my composition class. When we are learning how to write objectively, I project images of figures, including Christ, Satan, current politicians and entertainers, on the wall. I ask students to objectively describe these figures, emphasizing that I should not be able to tell how the students *feel about* or *judge* these figures. I get about a 40-50% success rate—in other words, at least half the students cannot get themselves out of the way when observing. If you want to be able to critically think effectively, you'll need to check your ego and remain open to what you are gathering.

2. What Is an Open Mind?

In any case (and in all three stages of the critical thinking process) you will need to keep an open mind, for example, by accepting the fact that not all four-year old blonde boys are bullies.

But what is an open mind? An open mind is a mind spacious enough to accept all matter of information—even information that is surprising, shocking, confusing, and contradictory to your previous knowledge or belief. I have a litmus test for students to see if they have an open mind. Can you explain a proposition, its support and warrants, so that someone can understand it? Sure. Here's the difficult part—can you explain a proposition, its supports and warrants, even if you do not assent to the proposition? Is your mind spacious enough to comprehend something you don't believe? Is it open enough to understand how someone can assent to a proposition you don't assent to?

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To really understand what it means to have an open mind, and to retain it, you must have some notion of what **ideology** is.

Ideology is difficult to define. Here's my definition, and it takes a while. First off, assume all aspects of culture can be traced back to some material need. Nutrition, clothing, shelter (needs of the individual body), reproduction, social interaction (needs of the species), are those basic material needs.

Over time, systems accrue; institutions evolve, in order to take care of those basic needs. The accrual of systems and values, the evolution of institutions into their present state, comprise ideology. Ideologies provide the structure of culture as well as its narratives. Let's take Valentine's Day, for example. Obviously, the material need is reproduction, but ideology tells us that it's really about love, romanticism, lovey-dovey interactions with a significant other who receives flowers and candy. Let's look more deeply at reproduction. Ideology tells us the appropriate way to reproduce is to establish yourself in the world, court or be courted, marry (with all the rituals and customs therein) and then reproduce.

But perhaps before reproducing you ought to secure a shelter. What is the ideology of shelter in America? It is the value of home ownership where you get a good job, work hard, get married, and buy a house. What does it take to buy a house? Take out an enormous loan that will last for 30 years in some cases. Then think about what happens to that loan. It gets bundled with other loans and sold as a security. Insurance companies insure the efficacy of those securities. Some will buy those securities as an investment. Others take bets on whether those securities will hold their value. In our economy, that original loan, let's say for \$100,000, might generate many more dollars' worth of fictional value in derivatives and market bets. Sound familiar? That kind of economic ideology of home ownership led to the market collapse of 2008.

Ideology isn't right or wrong; it just is. We all live according to ideology. Of course, people frequently believe that their ideology is the *correct* or *true* one. Think about wars. Ideologies organize people and machines to kill each other and each side claims righteous truth. This does not mean that all ideologies are as equally valid. Ideologies can be subject to objective or moral testing. Whether or not its adherents will accept the results of those tests is another issue entirely. *Ideology in/Ideology out.*

Here's another way to define ideology. You take all the energy each person has to achieve the basic material needs necessary for each person to live. Sum all the energy of all people in a society and call it "social energy." Simply put, *ideology directs social energy*. Want shelter? In America the energy is directed to home ownership. Have a deep spiritual need? That energy is directed to a number of religious practices. Want to reproduce? Better be adept at poetry starting with,

“Roses are red...”

If we are to be in the practice of having an open mind, we must be able to discern the ideology that shapes our understanding of the material world. Indeed, it is difficult to practice critical thinking on social, economic, psychological, and political issues without a deep understanding of what ideology is and what ideologies are at work in our culture and in us.

Let’s return to our example of daycare observation. Let’s say you adhere to an ideology that assumes females are biologically programmed to act a certain way as opposed to the way males are programmed to act. If you observe the children act in ways that swerve from that ideology, you may then process their behavior as being deviant rather than natural—you process their behavior to match what ideology has told you about their behavior. *Ideology in/ideology out.*

Once you understand what ideology is and how it shapes your world-view, you have created mental space, the open mind necessary to critically think. In addition, another benefit of an open mind is that an open mind is *curious* because it always can accommodate the new information we habitually seek.

3. How Much Gathering is Enough?

The answer to this question is always given by the telos. The simple answer is: Enough to fulfill the telos. The dishwasher problem required a few minutes. The paper for the child development class probably came with its own directions for the required amount of time to observe the children at play.

When a problem is given within a specific discipline, that discipline most likely has established protocols for the amount of information to be gathered, in what form, and by what means. In statistics for example, a variety of formulas can be used to determine the confidence interval according to a sample size relative to the targeted population. In the humanities, the amount of research required is less determinate. What is required is that the author’s position in the research is in context of already established research. In the natural sciences there are protocols for what constitutes appropriate research. Most research and scholarship is published in “peer-reviewed” journals. That way, the research and scholarship has been vetted, and, in many cases, commented upon and amended before being published. In other words, it has been processed by peers in the field before being applied.

The idea of “confidence” in the information you gather is both a specific objective value, and also a subjective one. In other words, in statistics you can conduct a survey that has a specific value for the confidence interval of your findings. If you’re working through a moral dilemma, that confidence value is

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much more difficult to determine and is based on the feeling that you have done enough reflection and consideration.

In practical terms, when you are given an assignment that involves critical thinking in college, how much gathering you need is usually included in the instructions. Those instructions are also included in protocols developed for research and industry in whatever field of endeavor you're engaged in. When you are critically thinking outside of pre-determined protocols, you'll have to rely on your experience and practice. If that sounds nebulous, don't worry. After the first go-around, if you have not gathered enough, or the right, information, you can revise your strategy. Remember, the gathering stage is **revisable** and **recursive**.

4. Gathering: What We Learned

- a. The purpose of the gathering stage is to collect pertinent information to be processed.
- b. You should have a strategy of how you will go about gathering.
- c. That strategy is revisable.
- d. You revise strategy in order to achieve maximum efficiency for minimum energy.
- e. The processes of critical thinking, the gathering stage, and revising strategies are all recursive processes.
- f. A recursive process is a large process composed of smaller processes that may be similar to the large one.
- g. You must gather information objectively, that is, without bias.
- h. *Bias in/Bias out.*
- i. Ideology is the foundation of a culture evolved to take care of material needs.
- j. Ideology directs social energy.
- k. Recognize ideology at work in your gathering.
- l. *Ideology in/Ideology out.*
- m. Keep an open mind.
- n. An open mind is a curious mind.
- o. Are there protocols for how you should go about gathering information? If so, follow them.
- p. If you don't get all the information you need to solve your problem, revise your strategy and gather again.

5. Gathering: A Case Study

It is difficult to choose a favorite pre-modern astronomer from the pantheon of Copernicus, Kepler, Galileo and Newton, but for “believe it or not” facts, no one beats Tycho Brahe. Brahe was a Danish nobleman (1546-1601) whose careful observation and measurement of planetary courses enabled Kepler to induce his three laws of planetary motion. But before we get to his gathering, let’s explore a couple of the oddities of Brahe’s life and death.

As a young man Brahe got into an argument with a peer over a mathematical formula. It was decided that they would resolve this conflict, not through mathematical induction, but a duel with swords. Brahe’s opponent struck the bridge of his nose clean off. Not wanting to live with a disfigured face, Brahe crafted himself a prosthetic nose. Historians speculated on what material that nose was crafted out of and discovered, after exhuming his body in the 20th century, that his nose was made of brass.

Brahe’s death is odd as well because it seems to be the result of excessive manners. Brahe was at a great feast that went on forever. Apparently, he had to urinate badly but felt bound by etiquette to remain in his seat until it was appropriate to leave the table. He died a few days later from a bladder that burst that evening during the feast.

Brahe was one of the last great naked-eye astronomers, for telescopes had not yet been developed. Brahe’s observations achieved a level of detail and accuracy that was astounding for his era. He was able to achieve this level of accuracy through careful planning, trial and error, patience, and precise instrumentation. He planned to exact specifications, and built, an observatory, Uraniborg, on a small island to afford him the widest range of views. Through dedicated engineering, he designed and crafted numerous instruments to aid his observations and calculations. Brahe’s work resulted in numerous tables which represented the movement of planets, comets and stars.

While Brahe was a genius at gathering information, he was not as skilled at processing that information. Kepler, Brahe’s student, clearly saw that Brahe’s data supported a heliocentric model of the solar system—the planets, and the earth, orbited around the sun. The Church, at the time, had declared that the heliocentric model was contradictory to the scriptures and ecclesiastical teaching. Brahe developed a hybrid model to explain the data—the sun revolved around the earth while the other planets revolved around the sun.

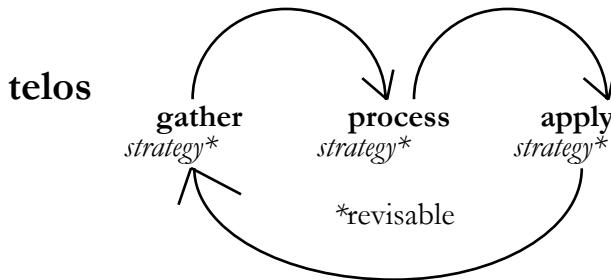
Brahe’s work also illustrates the role of ideology—his religious ideology prevented him from interpreting the information he gathered in the most accurate way. Kepler’s reasoning was more accurate because he was not bound by that

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Brahe's tables on the orbit of Mars used by Kepler

ideology. But it's not surprising that Brahe was held back by his ideology. If you think about it, his death was ideological. His body was telling him to pee, but the ideology of behavior for a nobleman kept him at the table until his bladder burst. I suppose there's a lesson there for us critical thinkers.

Many of Brahe's instruments can be seen as reproductions in the Cal-tech library archive and the Royal Danish library's exhibition on Tycho Brahe. http://www.kb.dk/en/nb/tema/webudstillingen/brahe_mechanica/introduktion.html



D. The Processing Stage

Once you have the pertinent information from the gathering stage of critical thinking, it is time you processed that information in order to solve the problem determined by your **telos**.

You already know that you need a **strategy** to process the information you gathered and that strategy is **revisable**. There are many ways to process information; we'll just look at a few broad categories and some examples in each category.

There's a rather large philosophical issue that we'll handle briefly here at the beginning. (If you want to explore the issue more deeply, look into Roger Penrose's *Road to Reality: A Complete Guide to the Laws of the Universe*.) The assumption we make here is that the universe is formalistic (I did not say *deterministic*). In other words, there is a form to the content of the reality we experience. In the process stage, we use strategies in order to reveal the form in the information we gather. Once that form is revealed, we can figure out how to apply what we learned from that revelation to fulfill our telos.

While we're on the topic of large philosophical issues handled briefly, it should be noted that computational theory explores the limits of machine-based problem-solving. It remains an open question in computational theory whether computers will be able to solve *all* problems (including the problem of deciding if computers can solve all problems!). But until such time as the machines take-over with their awesome critical thinking skills, we can trust our brain to process many of our problems (even though we may outsource much of the processing *to* computers).

1. Separating Information from Noise

No matter how efficient our information gathering process is, not all the information we gather will be usable. This principle is one of the foundations of Information Theory, developed by Claude Shannon in the 1930s and 40s. Shannon developed a mathematical model of how information is coded, transmitted, and decoded. One of his insights was that the transmission of information always includes noise.

Recall the case study where you are observing children interacting in a daycare? Maybe one day your notes read, “The boys and girls are waving their hands constantly in front of their heads today. Perhaps non-verbal communication.” Well, if that goes into your report for your child development class, it may seem like an insight into the close-knit group of children, but in reality it was just noise. One of the children had left a banana peel inside a plastic train three days previous which subsequently found its way to the bottom of the toy box where it served to host the reproduction of fruit flies. Those children are trying to play but have to keep swiping at those tiny pesky bugs flying around. That certainly would count as information to an exterminator, but for your telos, those hand gestures are just noise.

So the first thing you have to do is to determine what information you have gathered is usable. Here’s a message: Can you determine what is information and what is noise?

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If you found information, good for you. If you found noise, good for you too. If you didn’t, keep looking for the information in the noise. The clever student might say, “Here the noise is information as well.” Yes, there is noise in the information and information in the noise.

I go through this filtering process every time I write a research paper. First, when I take notes, not every idea of every source gets its own note. Second, when I begin to write, I start in the Invention stage by typing out all the notes I think will make it to the final draft of the essay. Not all the notes I wrote make it past this step. Then, when I draft the essay, I do not use all the notes I typed out. I find that writing a research paper is as much about leaving research out as it is putting research in.

Consider data mining as large scale information filtering. Programmers write code to sift through an unfathomable amount of information generated by online activity, data transmissions, and economic transactions in order to separate out usable information from noise. Whether the telos is the NSA looking for terrorists, or Macy’s searching for potential customers, this filtering activity is a

cornerstone, for better or worse, of modern life.

One of the more interesting projects involving the separation of information from noise takes place at the SETI Institute. SETI stands for Search for Extra-Terrestrial Intelligence. Now I don't endorse the notion that ancient aliens caused everything from the pyramids to velcro, but I keep an open mind about intelligent life elsewhere in the universe. The SETI Institute has set up a dish receiver array to collect radio waves from space. All kinds of cosmic phenomena produce radio waves, from quasars to black holes. One of the projects SETI engages in is analyzing these transmissions for signs of intelligent life.

I imagine the SETI Institute uses many of the processing methods we're about to discuss in order to find that needle in the cosmic-sized haystack. This reinforces another truth about processing in critical thinking—it often involves a number of approaches in order to fulfill the telos.

2. The Processing Stage Overview: What We Learned

- a. Our assumption is that it's a formalistic universe.
- b. Computational theory speculates on the ability of computers to solve problems.
- c. First you need to filter out noise from the information you've gathered.
- d. Data mining is a prevalent example of this filtering.
- e. SETI looks for information in cosmic radio waves.

3. Analysis

When we hear the word “anatomy” we think of a diagram of the human body, but that has not always been its primary definition. To conduct an anatomy used to mean to thoroughly examine the constituent parts of a whole. A famous example from the Renaissance was Robert Burton's *Anatomy of Melancholy* whose subtitle describes the process of anatomy— *What it is: With all the Kinds, Causes, Symptomes, Prognostickes, and Several Cures of it. In Three Maine Partitions with their several Sections, Members, and Subsections. Philosophically, Medicinally, Historically, Opened and Cut Up.* That is certainly an extensive examination. Another name for an extensive examination is **analysis**. Indeed, Burton includes an analysis of the book itself in the subtitle (“with three main partitions...”).

Burton's *Anatomy* is precisely what you do when you analyze. You take something apart in order to examine it. For example, you analyze in biology class

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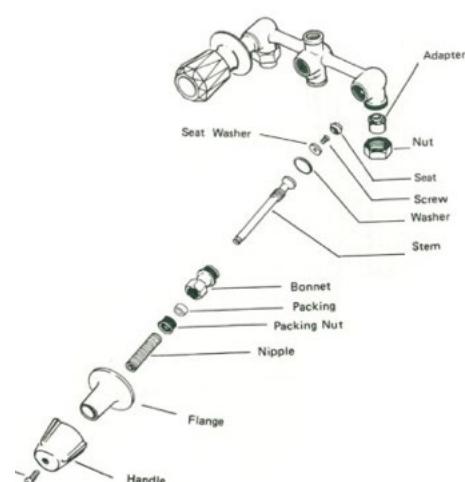
when you dissect an organism in pursuit of learning about it. As with all aspects of critical thinking, you have a reason why you are engaging in analysis—you take apart with a purpose in mind.

Why is analysis such an effective way of processing information? Perhaps it is because the information you need is often hidden in or obscured by the whole. So you take apart the whole to reveal the information you need. Two examples of this “hiding” in the whole are due to time-scale and space-scale. Let’s show what this means with time-scale.

Say you are a throws coach for a local track team and you have an athlete who is explosive and strong, yet she doesn’t seem to be throwing the shot-put near her potential. You keep watching her throw but you can’t figure out what is holding her back, so you decide to analyze her throw by recording her at practice. When you get home you play back her throw in slow motion—this way you can carefully examine each component of the throw, stopping the action whenever you want. At this attenuated time-scale you notice that just as she’s about to release the shot, she drops her right shoulder, losing significant power. What was hidden in real-time, was exposed in a slow-motion analysis. The information gained from the process of analysis can now be applied to the thrower to help her achieve her potential.

Problems also often hide in the space of the whole. Imagine you have a leaky faucet in the bathroom. When you stare at the thing, though, you just cannot see what is wrong. So you decide you need to take it apart to analyze what’s wrong (don’t forget to turn off the water source to the faucet first). You know what would be helpful as you do this? A diagram.

The diagram will not only help you take apart the faucet handle to diagnose the problem, it will also help you put it back together in the right order. A diagram such as the one to the left is a visualization of the analysis process.



Analysis can start after a very short gathering process or a long one. For example, consider an autopsy. The gathering is short—put the cadaver on the table and prepare the instruments. On the other hand, think about the SETI project—gathering radio waves from the universe is an enormous and

time-consuming gathering process.

It is important to note that analysis is often used in conjunction with some other processing technique. If you identify what's wrong with your leaky faucet, you still have to figure out how to fix it. Analysis can frequently be seen as a process that precedes the one we'll discuss in the next section: **synthesis**.

4. Analysis: What We Learned

- a. An anatomy is an extensive examination by analysis.
- b. To analyze means to take apart with a purpose.
- c. Sometimes information hides in the whole because of time-scale or space-scale.
- d. Diagrams can help us analyze.
- e. Analysis is often accompanied by synthesis.

5. Synthesis

If in analysis you take the whole apart in order to reveal the information you need, in **synthesis** you discover a whole that will contain the parts at hand. Analysis and synthesis are closely related because sometimes analysis only gets you half way to solving the problem—an autopsy can help to discover the *cause* of death, but the *manner* of death takes a synthetic act of mind. Consider the work of an archaeologist. He will analyze individual artifacts in order to discover what the culture was like that produced those artifacts. The movement, from individual artifacts to a vision of the culture that produced them, is synthesis.

Let's look at a simple example of synthesis. If the parts are red, blue, orange, green, what is one way to find a whole to contain these parts? It's easy—color. When the parts are more complex and more numerous, this process is not that obvious. Essentially, synthesis is uncovering an appropriate context that places components together. This can be a difficult activity because there can be many contexts that suggest themselves for the individual parts.

In many cases, providing a synthesis is an act of imagination—you visualize a context and check to see if that context accounts for what's known. This ability to visualize in order to check is one of the critical thinker's most powerful tools and can be used with a number of other processes—the **trial and error visualization**. One of the gifts given to us by our frontal lobe is that we are not prisoners of the present moment. We can imagine the results of an action before it occurs. In our trial and error attempts to reach a solution, we do not have to actually fail in order to learn from the failure.

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In deciding on a demonstrative example for synthetic visualization, I'll refer to personal experience—coaching youth football. A whistle is my favorite fashion accessory, accompanied by a matching clipboard.

Here are the individual components for a youth football team: 25 players of different size, skill, and motivation. 11 positions on defense, offense, and special teams (kickoff, kick return, punt, punt return); each position has specific responsibilities and physical demands. A league rule stipulates that each player must play at least eight plays a game. There must be a defensive and offensive arrangement within the rules of football. Determining lineups before each game was an exercise in synthetic visualization. I would make many draft lineups and compare them side-by-side to the roster before settling on one that fulfilled all the requirements. My strategy in constructing the lineups was revised according to the performance on the field and post-game analysis. As the season progressed this strategy became more efficient and less time-consuming.

Synthesis is not really something that you can teach as in “follow these procedures and you’ll reach the solution.” In reality, it takes practice, and what you need for practice are situations that require synthesis. Be on the lookout for these situations in school and your life. And, if you come across a foolproof offensive scheme for 6th graders, let me know.

6. Synthesis: What We Learned

- a. Synthesis is discovering a whole among the parts you've gathered.
- b. Synthesis is finding a context to provide a network of meaning for individual parts.
- c. Use trial and error visualization in order to choose an appropriate synthesis.
- d. Creating football lineups is an example of synthesis.

7. Analysis and Synthesis Together: A Case Study

Although this procedure is written for an assignment where the student must analyze a short story, it can be adapted for any research writing assignment. The key assumption is that *you do not know your thesis until you have done your research*. You start with a research question, but of course you cannot answer it until you have gathered all your information. If you choose a question you already think you know the answer to, it is most likely **ideology** at work.

Once you have your research question, you comb through sources finding pertinent information that will help you answer your question. Essentially, you are analyzing the sources to collect information. Once you have all that

information, from all those sources, you need to synthesize the information into a thesis that will then organize your essay. The following process requires analysis and synthesis and is what students writing essays of literary analysis use to complete their assignment.

Nine steps towards writing an essay of literary analysis:

1. Read the story with an eye toward a good topic.
2. Choose a topic--about any aspect of the story's form or content. Note that a topic is a general subject--you will need to turn that into a thesis later on in this process. Turn the topic into a question. For example, if your topic is characterization in "Where Are You Going Where Have You Been," turn the topic into the question: "How does Oates portray Arnold Friend?" Once you have turned the topic into a question, the rest of the steps will become easier.
3. Re-read the story with your topic as a filter. In this way, you will be uncovering passages from the story that relate to your topic. In other words, find passages that help you answer your research question.
4. Mark passages in the story that relate to your topic (and it would be helpful to, afterward, type these into a word processing file).
5. Analyze these passages and develop a thesis from them (the thesis is your arguable proposition about your topic).
6. Organize the passages in order to most effectively support your thesis (don't feel you need to follow the same order that they appear in the story).
7. Properly introduce, present, and interpret each passage. When you introduce a passage you are preparing your reader for it--giving them an idea of what to read it for. The presentation properly uses MLA citation format. The interpretation relates how that passage supports your thesis. Thus, all three elements of argument--CLAIM, WARRANT, SUPPORT, are included. The *claim* is your thesis. The *support* is each passage. The *warrant* (which connects support to claim) is how you read or interpret the passage so that it is used as evidence for your thesis.
8. Link your passages with proper transitions (each ¶ analyzing one or two passages) and write your introduction (see directions below) and conclusion
9. Revise.

Note that you take the story apart in order to generate a thesis which has been synthesized from your individual quotations.

You can use this technique to write any essay that requires you to support a thesis using sources. You analyze material in order to synthesize your thesis, and then organize your essay accordingly.

8. Finding Patterns

The book, *The Riddle of the Labyrinth* by Margalit Fox tells the absorbing true story of the attempt to decipher what was known as Linear B—a script found

Spoiler Alert: Ideology was at work in deciphering Linear B. Archaeologists assumed that the Minoan culture that produced Linear B was far advanced from other Greek cultures at the time, so they thought they were looking at a unique language. Turns out it was plain old Greek phonetically transcribed with Minoan script.

in-situ and in tablets on the island of Crete dating from the second millennium B.C.E. At least the Egyptologists had the Rosetta Stone to help them decipher hieroglyphics. Scholars who attempted to decipher Linear B had only the script itself. It was eventually deciphered by a British architect named Michael Ventris, but only after long, arduous, and patient work by the American Alice Kober.

Kober essentially constructed a home-made database out of cigarette boxes to file and sort the script, as well as organizing the script's signs into tables and charts. Tragically, she was nearing decipherment at the time of her death. The story of her work and the work of others in deciphering Linear B is an exemplar of how to find a pattern in the information you gather.

You can look at attempts to find a pattern as a kind of decoding. The information on the surface is a mask for the structure (or code) underneath. Finding a pattern is similar to synthesis (in some cases it is synthesis). In synthesis you have to imagine a context that gives your information meaning. In finding a pattern you have to imagine a pattern that gives your information meaning. For example, I will list a series of numbers; can you find the pattern that orders their sequence?

75 15 25 5 15 3

How do you go about solving the problem? Certainly Alice Kober didn't just stare at facsimiles of the tablets until she figured something out—she started organizing the information. In the synthesis section, we discussed trial and error visualization. Organizing information externally (and provisionally) is a way to conduct trial and error visualization. Let's do that with this sequence. Start with the first two numbers. What is their relationship? Yes, $3 \times 5 = 15$. Let's put "X" between those numbers. Do any other numbers share the same relationship? As it turns out, yes. Let's mark them in the same way. Now let's look at the second and third number. What is their relationship? Yes, take 10 away from 15 you're left with 5. Let's mark that underneath the line of numbers, as well as any other pairs of numbers that share that relationship.

X5	X5	X5
75	15	25
—10	5	15
		3
		—10

We have found the pattern. You multiply by five then subtract by 10.

One of the reasons we may want to find a pattern is to make a prediction—consistency is what makes a pattern a pattern. Once we have discovered the pattern controlling the numbers above, we can apply the pattern infinitely forwards or backwards. In the same way, if more tablets of Linear B were found, they could be immediately deciphered. External visualization is effective

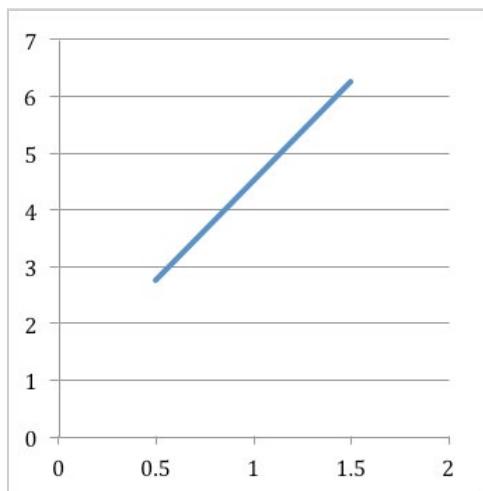
in almost every case of pattern detection. Why? Because our visio motor system has evolved to be looking for, and analyzing patterns. (Is that a tiger in the grass or just a pattern of shade?) If you want to be successful at finding patterns, then you'll need to become adept at turning the information you gather into a graphic representation.

Here is a set of ordered pairs. What's the easiest way to reveal the pattern? (.5, 2.75); (1, 4.5); (1.5, 5.25). A graph will show the logic beneath these ordered pairs.

(It's a linear equation $y=3.5x + 1$.)

Spatial and temporal information is especially amenable to graphic representation because both can be converted fairly easily into two dimensions—think of a train schedule and a map. Indeed, the most effective models of graphic representation can reveal patterns in space-time, which is four dimensions. The ability to create graphs, scatter-shot plots, time series illustrations, small multiple representations, tables and charts, will greatly enhance your ability to detect patterns. The creation of these visual aids is always provisional—that is, part of a trial and error procedure—the strategy at each stage, of each process, is revisable.

Not all information is given visually. Think of listening for patterns in music (if you can read music though, you can find patterns by looking at the score). Again, you are aided by your oculomotor system that is attuned to patterns as well. Our oculomotor system is sensitive to patterns in order to separate information from noise.

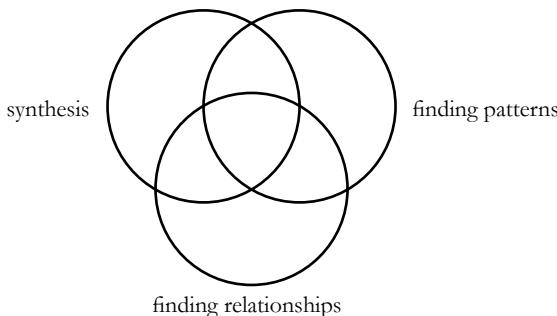


9. Finding Patterns: What We Learned

- a. The story of deciphering Linear B.
- b. Finding a pattern is a kind of decoding.
- c. Finding a pattern is looking beneath the surface mask to discover the hidden order.
- d. Organize your information externally and provisionally.
- e. Graphic representation helps you organize and visualize your information.

10. Finding Relationships

Relationships can be found in patterns, and through synthesis—all three processes are related and can be identical.



Now, can you remember back to the chapter on rhetoric, the section on reasoning, and use your synthetic imagination to think of a large circle that will contain all three circles in the Venn diagram above?

Yes, **inductive reasoning**. When we engage in inductive reasoning, we move from a number of specific cases in order to derive a provisional rule that governs those cases. This movement from specific to general is synthesis. The grounds for moving from the specific to the general may be the detection of a pattern or discovery of a relation.

Therefore we use inductive reasoning to find relationships. What kinds of relationships are there to find? Innumerable kinds. Things can be related

temporally, spatially, structurally, and analogically. They can be related according to their origins, their destinations, and their routes to get there. Think of it this way—if you have two things that share a category of attributes, those things can be put into relation.

To consider the mathematical limits of relations imagine that you have information you've gathered into a database. The database has 100 records and each record has 10 fields. Each field is a separate attribute or feature of the whole the record represents. First, you can combine those 10 attributes in 2^{10} possible ways within each record (take away one for the empty set and 10 for sets with individual attributes—1013 ways, more precisely). This does not mean that the attributes *are* related in 1013 ways, but that is the limit of their possible relations. Second, how many ways can we relate the 100 records, each with 10 attributes? It's a number too big to count.

Finding relations is only limited by the complexity of the things we want to put in relation, and our imagination. According to Percy Shelley, the 19th century English poet, the work of the imagination is to reveal the “unapprehended relations of things.” In other words, the creative imagination can see relations no one else sees.

When we critically think, we are usually not looking for any kind of relationship, but a specific one. A common relation that we gather information to discover is a **causal** relation. In a causal relation, one phenomenon causes another—one phenomenon is the input (cause) and the other the output (effect). For example, if you wanted to check to see if prison recidivism decreased when the inmates had access to education, you would check the recidivism rates among prisoners who received education and those who didn't. Education would be the input and recidivism the output. The clever student may warn, “Correlation isn't causation,” and is correct—to an extent. In the example above, maybe only inmates with sentences for minor, nonviolent crimes were offered education. Perhaps it was the kind of crime committed that determined recidivism rate and not education. You need to scrutinize all factors before determining a causal relation. And though it is true that correlation does not mean causation, remember that there is no causation without correlation.

If your information gathering is a large dataset, you can use the statistical method of regression analysis to determine causal relations among variables. Essentially you construct a mathematical model of the reality you intend to analyze. That model includes variables that signify attributes of the world you want to query to test if they are causally related. If your model is constructed properly, regression analysis will help you determine those relations. Regression analysis is the kind of processing where computers make our critical thinking

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much more efficient.

Another kind of relation is **taxonomic**. Taxonomy is the discipline of classification. Imagine your job is to go to a state park and, over a week period, chronicle all the wildlife you see while walking the trails. One way to organize that information would with biological taxonomy. That taxonomic organization is set up according to common factors in the structure of living beings. By using taxonomic organization you would show the relationship between the environment and the species in it.

Taxonomy is essentially a form to be filled to show relation. Regression is an automated statistical equation to discover relations. How else can you discover relationships within information you've gathered? It is no different from synthesis and finding a pattern—visualize the information externally. The Venn diagram at the beginning of this section (unwieldy though it is) does exactly that—it shows the relations among the three kinds of processing. It may take a number of strategies and revisions to find the kind of graphic representation that reveals relations, so it helps to be deliberate and patient.

A trivial example will help illustrate this. Imagine your house is heated by gas and you want to scrutinize your energy usage. Different **time-scales** will reveal different kinds of information. For example, if you graphed usage week-to-week, a relation would reveal itself—you use more energy in the winter months.

Now that the general relationship between energy usage and time is established, you can decrease the time-scale for more precise information about relations. Take the 10 weeks of heaviest energy usage and list the amount of energy by day of the week—perhaps a relationship will be revealed about which days of the week you consume the most energy. You can do it for hours as well. The point is that these relations are only revealed if you choose the right kind of graphic representation with the right kind of interval scale. The same thing goes for spatial scale. If you wanted to discover where the ants in your cupboard are coming from, you wouldn't use a map of the United States—besides, you can spot a Missouri ant a mile away.

If you're interested in the math of relationships, find an introductory text to set theory and discover how infinite sets can be put in relation. If you're interested in using the creative imagination in the way that Shelley describes, read literature. A fresh metaphor always reveals the “unapprehended relations of things.”

11. Finding Relationships: What We Learned

- a. Synthesis, finding patterns, finding relationships are all examples of

induction.

- b. There are innumerable relationships to be found based on common attributes.
- c. Possible relationships can grow exponentially.
- d. You will often look for causal relationships between inputs (causes) and outputs (effects).
- e. Correlation isn't causation but it's present in every example of causation.
- f. Regression analysis uses formulas and computing to discover relationships among inputs and outputs.
- g. Differing scales in graphic representation can reveal relationships.
- h. Set theory is a mathematical discipline of relationships.

12. Finding Relationships: A Case Study

At the end of August in 1854 a breakout of cholera occurred in central London. Cholera then was a fatal disease characterized by catastrophic diarrhea. This was the time when epidemiology was in its infancy. It was thought that cholera was spread through the air, maybe even from vapors emanating from the buried whom died of the plague (note the faulty causal thinking—because some attributes of the plague and cholera are associated, the onset of the disease is assumed to be causally related).

The information from this account is taken from Edward Tufte's book *Visual Explanations*.

Dr. John Snow had been studying epidemics and gathered the death certificates of 83 people who had died during this particular outbreak. As Edward Tufte points out, Snow did not plot these deaths in time series graphs for those would not reveal a cause. Dr. Snow plotted these deaths on a map of central London that included the locations of water pumps.

When Snow plotted these deaths on the map he discovered that the vast majority of those who died of cholera died in the vicinity of a water pump on Broad Street. Snow made a presentation of his findings to the area leaders and they removed the handle of the Broad Street pump. The epidemic petered out. There is some debate about whether or not the epidemic was subsiding when the pump handle was removed, but Snow's graphic representation most assuredly revealed the relationship between contaminated water consumption and cholera.

There were a few anomalies in Snow's map that he investigated and explained. For example some young girls who did not live in the Broad Street area died during the epidemic. It was discovered they went to school nearby and would

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drink from the pump on their way home. A brewery a mere block from the pump experienced no deaths among its workers. Can you guess why? Yes, gentle reader, those workers drank beer on their breaks.

Snow's work in processing the information he gathered, those death certificates, demonstrates the importance of finding the appropriate graphical representation to reveal relationships. In addition, his work points to the application stage—because his work was accurate *and* persuasive, he was able to convince authorities to take action. Tufte compares Snow's work to the graphic representations attempting to show a causal relationship between O-ring deterioration and low temperatures during launches of the space shuttle. Those graphics were not as accurate as they could have been and were not persuasive at all. As a consequence, the space shuttle Challenger was launched in freezing temperatures and was destroyed 73 seconds later, killing the seven crew members. Sometimes finding the correct relationship in information is a matter of life and death.

13. The Workspace

It should be apparent now that almost every example of processing demands an external workspace. Why is this? Because critical thinking problems require you to account for many variables at once and it is very difficult to keep all of them organized in your “working memory” (think of the brain’s RAM). When we externally visualize the information through graphic representation, our focused sight keeps track of and organizes information. This is the same way written language functions—it is an external workspace as well. Using an external representation of information allows us to move from gathering to processing in fractions of a second. It is also very recursive because we can quickly revise our strategies with each glance. We constantly revise, active in our external workspace, as we question and sharpen the efficacy of our strategies. When I write poetry, the poem itself is the workspace, rewritten, slightly altered, many times in a notebook. I look forward right now onto an external workspace, a computer screen, lit up in a Microsoft Word file called “criticalthinking3.”

Not all workspaces are visual. A car is the external workspace to a mechanic. Musicians use their hearing and kinesthetic sense while playing their instruments. Athletes use their kinesthetic sense as well—their environment is the workspace interacting with their nervous system.

You should prepare an external workspace when you critically think.

14. Rule-based Processing

Rule-based processing is based on a **deductive reasoning**. As you may recall, deductive reasoning dictates that if the premises are true, the conclusion must be true. In a basic sense, deduction applies a general rule, already established, to a specific case. You show the general law implies (because it applies to) the specific case. Where inductive reasoning leads to a conclusion within a confidence interval, deductive reasoning leads to conclusions which are always true—within the structure of the deductive system.

Let's start with a simple example. Given that an integer N is even if $N/2$ is an integer. Then 8 is even and 9 is not, because 4 is an integer and 4.5 is not. This rule applies to an infinite amount of numbers (but not all numbers).

Here's another simple illustration of rule based processing. How do you go about solving this problem? $4^2 \times (8-2) + 3 \times (9-2) = ?$ Which operations do we do first? Since math is a rule-based system, you do not need to worry—just apply the problem to the already established rules for operations:

1. Parentheses
2. Exponents
3. Multiplication and division
4. Addition and subtraction

$$4^2 \times 6 + 3 \times 7$$

$$16 \times 6 + 3 \times 7$$

$$96 + 21$$

$$117$$

This does not mean you cannot be wrong when using deduction. You could draw inferences from faulty premises or infer poorly from sound premises. Some logical proofs are pages of complex notation; errors can occur. If a proof is valid though, it will check out as valid every time, no matter how many times checked.

It's impossible to discuss rule based processing without mentioning computers. I'll leave it to a programmer to discuss how to gather, process, and apply when solving programming problems. I suspect that it's important for college students to learn how to program, or at least be introduced to computer logic. A computer can only do what it's programmed to do—it follows the code it's given, given its hardware. It operates deductively.

To get an idea of what these classes of problems are like and how they are related, take a look at the online Complexity Zoo which organizes problems and their classes. Its “zookeeper” is Scott Aaronson whose book *Quantum Computing since Democritus* is a good introduction to these issues. www.complexityzoo.uwaterloo.ca

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The field of computational complexity is an interesting use of deductive reasoning—its proofs show how one problem is like another problem is like another problem. The telos often is not to solve a problem by computation (the problem may be presently unsolvable), but to show that if you could solve that problem, you could solve all the problems in that computational class. It's an abstract and demanding exercise in problem solving without solving the problem. Within that procedure is deduction distilled—showing how all cases in a class, or are one case.

Logic and the rules of inference govern deductive reasoning. For example, one basic rule of inference is that If N implies M and you are given N, then M is implied. Let's fill the letters with specific cases. N=humans and M=rational animals. Therefore if Joe Pellopi is a human, he is a rational animal. What else can we fill these letters with? If N=humans and M=having DNA then if Joe Pellopi is a human, he has DNA. Essentially the rules of inference turn logical structures into formulas whose variables can be assigned to an infinite number of particulars—the formulas are foundational and given; they do not change.

Deductive reasoning is not only useful in closed systems like mathematics, computer programming and symbolic logic, but also in other modes of processing. It can be used to test the logical consistency of theses, even if the theses are drawn inductively. Imagine that through your gathering and processing you have found a relationship between gaming over 10 hours a day and a 5% drop in IQ. What does this imply? Because IQ tests purport to provide a quotient of the brain's processing power, your thesis logically implies that gaming has an effect on the brain of the gamer. To follow up on your thesis you may want to look into neuroscience studies that show the effect of gaming.

Let's look at another example of implication (this time negative) in “the dismal science,” otherwise known as economics. Classical macroeconomics tells us that as the economy's money supply increases, so does inflation (If M then N). (The simple definition of inflation is “too much money chasing too few goods.”) But because the economy is a *very* open system with numerous variables and all kinds of stochasticity (randomness), the logical formulation *An increase in the money supply implies an increase in inflation* is not 100% guaranteed.

Since the recession of 2008, the money supply has increased but there has not

Can you use deduction to explain why when the dollar becomes more valuable relative to other currencies, the price of goods goes down? Think your way through it this way. Imagine that a dollar used to buy one Chinese apple. Say the dollar becomes 50% more valuable compared to the Chinese yuan. To you, the dollar is still a dollar, but it can now buy an apple and a half. The price of the apple has decreased just because your currency is the dollar.

been the kind of inflation associated with that increase. This fact *implies* that there are other factors at work. First, the American workforce's productivity has a dampening effect on inflation, as does the strong dollar. Furthermore, banks and corporations are holding enormous amounts of cash—if that cash isn't circulating, it won't lead to inflation.

Deductive reasoning can also be used outside closed systems to test the logical consistency of theses. A Congresswoman argues for a flat income tax because, she says, the current progressive taxing system becomes more unfair the more money you make. “The government should not give special benefits to one group or another,” she argues. On the other hand, she fights for enormous tax breaks for corporations whose headquarters are in her district. You are running against her in an election and during the debate you make sure to note the logical inconsistency of her position. “Are you a socialist?” she asks. “No,” you reply, “I am a deductive logic-ist!” The crowd roars its approval and you win by a landslide.

By the way, which do you think is more powerfully persuasive to people, ideology or logic? If you said “ideology,” you are probably right. How do we change that? If you said, “teach critical thinking,” you are certainly right.

It's helpful to sharpen your deductive skills by practicing on problems within manageable deductive systems. Some problems I give students in Composition class are derived from Raymond Smullyan's book *Lady or the Tiger?* Here's one of them:

You are an insane asylum inspector. In the asylums you inspect, the inhabitants are patients or doctors. The patients and the doctors can be either sane or insane. Those inhabitants (patients or doctors) who are sane always tell the truth. Those inhabitants (patients or doctors) who are insane always lie. Your job is to discover if there is something wrong with the insane asylum.

Before we go any further, let's consider what the inspector might be looking for. What is the case when there is something wrong with the asylum? When a doctor is insane, or a patient is sane. The first step in these types of problems is to figure what we are looking for.

Here's a situation that demands an answer. The inspector visits one asylum whereupon the inhabitant he interviews says one sentence by which the inspector can tell that the speaker is a sane patient; therefore something is wrong with the asylum. What is that statement?

So, we are looking for a single statement. We ought to prepare a work space. What would be a good workspace for this problem? Start by figuring out what we know and how we can use it. We know that any individual inhabitant can be

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one of four things: an Insane Doctor (ID), Sane Doctor (SD), Insane Patient (IP), Sane Patient (SP). Ironically enough, probably the best strategy to solve this deductive problem is to use inductive processing. We can try some individual cases to see which one satisfies our general requirement. What would be the simplest, most intuitive statement to start with? “I am a sane patient.” Let’s put together a workspace.

I am a sane patient.

SD

ID

SP

IP

Can a SD make that statement? No because it would be a lie and sane inhabitants don’t lie. Can an ID make that statement? Yes because it would be a lie and insane inhabitants always lie. We can now fill out the rest of the chart.

I am a sane patient.

SD No

ID Yes

SP Yes

IP Yes

Can you now tell why, “I am a sane patient” is not the right statement? Three of the four possible inhabitants can make that statement.

By trying out a case, we have properly set up our work space as well as isolated what we will be looking for: a “Yes” next to “SP” and a “No” in the other three slots. Now, if the question were, “What is a statement that only the sane doctor cannot say?” you have your answer above and, as it turns out, a helpful hint to the original question.

This practice problem again highlights the necessity of developing a workspace to organize the information that you are given and to set up the solution. It would be very difficult to hold the attributes of all four possible inhabitants in your head at once, as well as the possibility of their answers. As should be apparent by now as well, when you have set up your workspace and you cannot find the solution, you have to revise your strategy by re-designing the workspace.

If you can recall your experience in high school geometry, making deductive proofs is hard, and sometimes frustrating, work. The benefit is that when you finally get it right, all the elements fall into place, and the feeling of personal satisfaction is great. And maybe the best thing about it is, every time you look at your solution, you’re still right.

15. Rule-based Processing: What We Learned

- a. Deductive reasoning is rule-based processing.
- b. Mathematics is an example of a deductive discipline.
- c. Computers operate on rule-based processing.
- d. Computer complexity seeks to show how problems are related within a class and how those classes are related.
- e. Rules of inference govern logic.
- f. You can apply logic to these formed inductively.
- g. Economic reasoning works through chains of implications.
- h. Use logic to test the consistency of intellectual positions.
- i. Set up truth tables when applicable to logic problems.
- j. Rule-based processing is difficult but rewarding.

E. Creation and Innovation

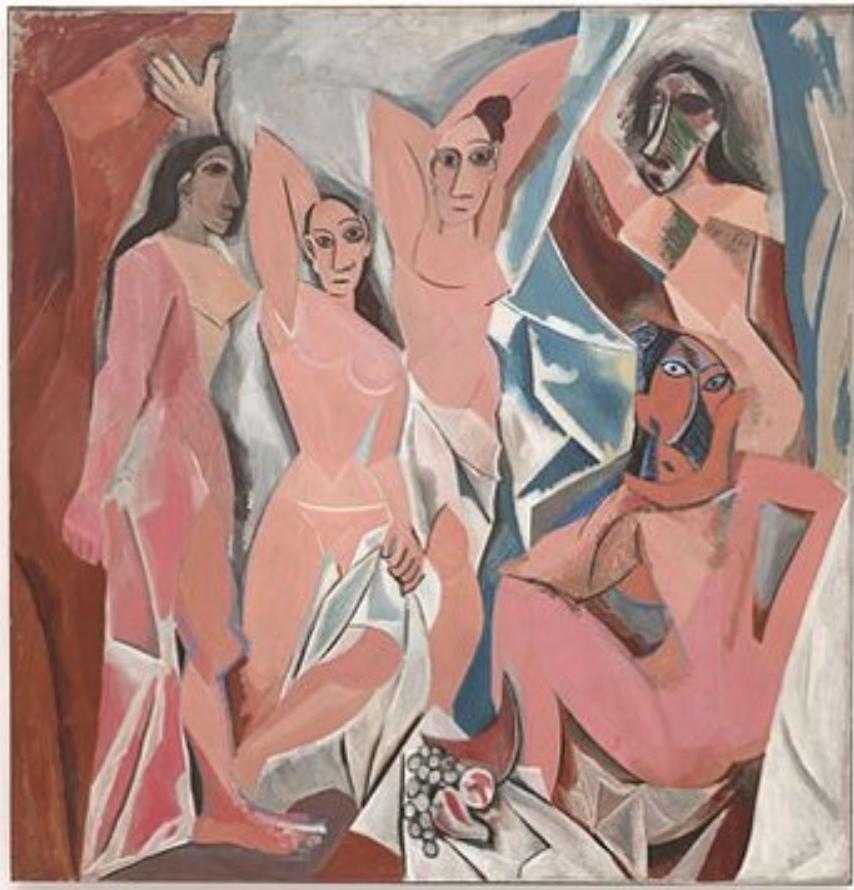
Sometimes for the critical thinker, the telos is to make something better, or to create something original. We can adapt some of the processing strategies we've discussed to show how they apply to the telos of creation and innovation. But before we look at these strategies, it would help to mention two attitudes toward the process that, in my experience, are necessary to innovate and create. First, be brave. **No fear**—do not be held back by ideology, by contempt of failure, by convention. Do not be held back by the desire for attention—it is limiting. Second, because you are released from fear, you are free to **play**. A ludic spirit is willing to try anything, to take risks. Creativity follows those who are playful and without fear.

1. Analysis

A term from 20th century literary criticism is useful here—deconstruction. When you deconstruct something creatively, you take it apart to uncover hidden assumptions and to reveal something brand new about the thing you take apart. You make something new through analysis.

Our example will come from the painting movement called **cubism** during the first quarter of the 20th century. Cubist art foregrounds the two-dimensionality of the medium (painting on a canvas) instead of trying to trick the viewer's eye into thinking that she is looking at three dimensions.

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Although innovative, can you detect what is ideological about this painting?

Cubist painters deconstructed (analyzed) a three dimensional scene (or sometimes a four dimensional scene) and, through the technique of collage, reassembled the geometric planes of observation into a compositional whole. Let's look at a painting by Pablo Picasso (1881-1973), *Les Demoiselles d'Avignon*, from 1907 that helped usher in Cubism.

This painting was made before cubist principles were conventionalized, but the analytical style is in play. Notice how these figures are abstracted into basic shapes that signify planar relationships as well as “female body.” Can you find the shaded triangle that is part of the figure in the lower right’s back? The convention of showing painterly skill by draping cloth over a figure is transformed into a few shapes on the lower left.

I suppose the painting is jarring if you desire to see the majesty of the human body, but the constructed composition (out of analyzed elements), how the angles

and colors interact, is a different kind of beauty. By deconstructing conventional expectations for a painting, Picasso teaches us how to look at art in a new way. There's one other thing I'll mention about the painting. The two women along the right edge of the painting have their faces rendered in a very stylized way. Picasso rendered their faces as African masks, finding a powerful vitality there.

2. Synthesis

When the transistor was invented in 1947 it paved the way for the electronic age. A transistor uses a semiconductor, like silicon, to amplify a signal or function as a switch. Even though the transistor was great improvement over the vacuum tube, there remained pressure to keep miniaturizing the components of a circuit.

The two main sources for this section are a short film by Texas Instruments which contains interviews with the principals of the invention of the Integrated Circuit and a PBS website accompaniment to its documentary *Transistorized*.

<http://www.pbs.org/transistor/index.html>
http://www.ti.com/corp/docs/company/history/timeline/semicon/1950/video/ICInvention58_300k.wmv

a

Jack Kilby was a new hire at Texas Instruments when the company took its two week vacation en masse, so he was not afforded the time off. Alone with time to think, he had an idea for making an integrated circuit—a synthesized circuit made of one piece of material. His gathering stage was several months of sketching in his notebook before he was ready to assemble. He did so on Sep 12, 1958 and successfully tested the first integrated circuit.

At nearly the same time, Robert Noyce, who was working for Fairchild Semiconductor, developed his own integrated circuit. He went on to found, with Gordon Moore, the Intel Corporation which makes microprocessors for computers.

How many integrated circuits do you imagine there are within a 10 foot radius of your body right now? Integrated circuits were revolutionary and have deeply impacted our lives. The development of the integrated circuit also highlights two relevant issues. First, the inventors were free to gather and speculate for a long time before they built their prototypes. Second, integration is an act of synthesis—all the separate parts that were used to make circuits cold now be fabricated on a single chip.

3. Finding Patterns

The motif of this section is *varying patterns*. If you want to create something new, take an intact pattern and vary it, loosen it, transform it. Something completely new will result.

For creation through varying patterns, we'll look at an example from poetry and music.

Wallace Stevens's poem, "Thirteen Ways of Looking at a Blackbird" puts a blackbird in every section and develops variations of themes on perception, image, and object. I'll reproduce the first seven.

I

Among twenty snowy mountains,
The only moving thing
Was the eye of the blackbird.

II

I was of three minds,
Like a tree
In which there are three blackbirds.

III

The blackbird whirled in the autumn winds.
It was a small part of the pantomime.

IV

A man and a woman
Are one.
A man and a woman and a blackbird
Are one.

V

I do not know which to prefer,
The beauty of inflections
Or the beauty of innuendoes,
The blackbird whistling
Or just after.

VI

Icicles filled the long window
 With barbaric glass.
 The shadow of the blackbird
 Crossed it, to and fro.
 The mood
 Traced in the shadow
 An indecipherable cause.

VII

O thin men of Haddam,
 Why do you imagine golden birds?
 Do you not see how the blackbird
 Walks around the feet
 Of the women about you?

A further iteration of what Stevens is doing here—taking a theme and varying it—can be done with Stevens’s poem itself. For example, create a new poem called “Variations on a Theme By Stevens” with the line, “The beauty of innuendoes” as its epigraph.

Music often takes melodic themes and varies them. The improvisatory genius of jazz is especially adept at this (for a more mathematical approach to variations, listen to Bach). Often, jazz takes the 12 bar or 16 bar structure of the blues and transforms it rhythmically and sonically in creative ways. The example that I’ll provide links to is not the transformation of a blues tune, but jazz saxophonist John Coltrane’s transformation of a sweet melody from Rodger’s and Hammerstein’s musical *The Sound of Music*.

Coltrane creates 13 minutes of jazz out of Rodgers and Hammerstein’s two minute and thirty second show tune, yet in all that free improvisatory play, he never loses the basic melodic theme. (McCoy Tyner on piano.)

Julie Andrew’s vocal version:
<http://www.youtube.com/watch?v=33o32C0ogVM>

John Coltrane’s transformation:
<http://www.youtube.com/watch?v=qWG2dsXV5HI>

4. Finding Relationships

When we discussed how to find relationships as a critical thinking process, the focus was on ways to find patterns in information you’ve gathered. In considering the broad assumption at the beginning of this chapter on processing, we assume that these relations are implicit in the structure of our formalistic universe. But

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what about putting things together that have hitherto no relationship with each other? That is the work of metaphor.

Renaissance alchemists saw the universe metaphorically. There was a base ambition for alchemists: they wanted to turn objects, such as lead, into gold. But they also were forerunners of scientists who experimented in order to create. Their belief was that the cosmos was held together by sympathetic correspondences and it was a form of magic to reveal those hidden correspondences. Remember Shelley—art reveals “the unapprehended relations of things.” Freud accomplished this when he conjured a relationship between dreams and the psyche. Adam Smith did this when he conjectured on the cause of the wealth of nations. Gertrude Stein did this when she contrived a way to write that followed the flow of cognition. In Western culture it’s hard to find a mind more congenial to putting things together in new ways, in making metaphor, than another figure from the Renaissance--Shakespeare.

You can go to any play by Shakespeare to mine metaphors, but I choose a passage from *Macbeth*. Macbeth and his wife have plotted and murdered their way nearly to the kingship, but things are falling apart. Mad with grief and guilt, Lady Macbeth kills herself. When Macbeth finds out, he speaks these words:

She should have died hereafter.

There would have been a time for such a word.

Tomorrow, and tomorrow, and tomorrow,

Creeps in this petty pace from day to day

To the last syllable of recorded time,

And all our yesterdays have lighted fools

The way to dusty death. Out, out, brief candle!

Life's but a walking shadow, a poor player

That struts and frets his hour upon the stage

And then is heard no more. It is a tale

Told by an idiot, full of sound and fury,

Signifying nothing.

A quick inventory of these metaphors:

1. tomorrow “creeps”
2. time moves as words in history books, “last syllable”
3. yesterday glows from the past to light our way to death
4. life’s a brief candle
5. life’s a walking shadow
6. the shadow’s an actor
7. life is a tale

8. the teller of the tale's an idiot
9. life's a tale that's full of sound and fury.

If we look at this speech we see the energy of Macbeth's mind as it ranges over these desperate and sober musings. We can't help but think of the play itself that reflected his and his wife's machinations to gain power. For all the creativity of this passage in making metaphor, it ends signifying "nothing," which is exactly what Macbeth has.

The ability to put things together in a new way is at the heart of creation and invention. You can try it when you cook, when you dance, when you dress, when you write...when you do anything. Living creatively is a practice of forging new relations.

5. Rule-based Processing

Alfred North Whitehead and Bertrand Russell were two British philosophers who had a grand ambition. Their goal was to use axiomatic symbolic logic, with a foundation of set theory, to derive a deductive system to account for all of mathematics. If they were to achieve their goal, they would demonstrate that mathematics was a closed, complete, and consistent system.

The fruit of their intense labor was a three-volume book, published first in 1910, called *Principia Mathematica*. *Principia Mathematica* was an immense intellectual accomplishment but there were some questions and issues that were not settled. It was their belief that, over time, these problems would be solved.

One of these issues plagued the founder of set theory, Georg Cantor, as well. The paradox, in a nutshell is: imagine you have a set, N , which is the set of all sets that do not include themselves as members. If N does not have itself as a member, then it belongs in the set of all sets that do not include themselves as a member. Now it's in the set, which means it has itself as a member. We have reached a contradiction. My naïve way at looking at the set of all sets paradox is that if you build any closed referential system you, if you press long enough, can find its limits but can't, within that system, leap beyond those limits—you can't see beyond the system that grants you sight.

How about building another system to see beyond the first system? You're just delaying the inevitable for you will reach the limits of the second system as well, which means building a third system and so on until the universe winds down.

In 1931 a German mathematician and philosopher, Kurt Gödel, proved that Whitehead and Russell's entire project was impossible to complete. He proved

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that if a deductive system is consistent, it couldn't be complete (that is there would be propositions generated by the system that would not be logically accounted for). He also proved that for deductive systems large enough to account for number theory, then the system wouldn't be consistent.

His proof is a wonder of logical genius and, in a way, borrows its concept from the set of all sets paradox by inputting the system itself as a proposition to be proved. Mathematically, it's beyond my reference system (my brain) to explain, but fortunately, there's an old rhetorical paradox that it is similar to.

Gödel's proof was akin to the old Cretan's paradox. One rule of inference is that any proposition A cannot be A and not-A at the same time. For example you can't be here and not-here at the same time (unless you're in quantum superposition, but we'll ignore that possibility). The Cretan paradox goes like this: what if proposition A is given by a Cretan (someone from the isle of Crete) and the proposition is "Cretan's always lie." So if Proposition A is true it's a lie, and if it's a lie, then it's true—we have a logical paradox. Gödel did the Cretan on *Principia Mathematica*.

I include the story of Whitehead, Russell, and Gödel in this section on innovation and creation because Gödel's proof is one of the most important and innovative ideas of the 20th century and has profound implications for computation and Artificial Intelligence. Secondly, this paradox about systems and frames of reference has been fruitful terrain for science fiction writers like Philip K. Dick whose shorts stories gave us *Blade Runner*, *Total Recall*, *Minority Report*, and *Through a Scanner Darkly*. This kind of thinking around, and about, the edge of what is known and knowable yields much creative insight.

6. Creation and Innovation: What We Learned

- a. Have no fear when creating.
- b. Play when creating.
- c. Deconstruct as a way to construct.
- d. Cubism is an example of creative deconstruction.
- e. Creative synthesis integrates, puts new things together in a unified way.
- f. The integrated circuit is an example of such synthesis.
- g. Innovators need plenty of free time to gather.
- h. Take patterns and vary those patterns to make something new.
- i. Wallace Stevens's poem, "13 Ways of Looking at a Blackbird," conducts variations on the themes of perception and image.
- j. You can take something already created and use it as a theme to conduct variations on.

- k. Jazz transforms rhythm and melody through improvisation.
- l. John Coltrane turns a two minute thirty second show tune into a 14 minute jazz masterpiece.
- m. Metaphors put things in new relationships.
- n. Alchemy tried to take metaphors literally and materially.
- o. One passage from Shakespeare has 9 metaphors in 12 lines.
- p. Can the set of all sets have itself as a member?
- q. Gödel's proof shows the limits of large deductive systems.
- r. His proof is a mathematical version of the Cretan's Paradox.
- s. Science fiction and speculative art plays on the furthest edge of referential systems.

7. Creation and Innovation: A Case Study

For classic rock lovers, Brian Eno was one of the early members of the glam rock band Roxy Music (which also gave us Bryan Ferry). If you're a member of the younger club and rave set, Brian Eno's innovation in producing played a fundamental role in the development of EDM. He has produced bands such as Cold Play and U2 and is known as an innovative and creative producer, arranger, and engineer.

A technique that Eno uses to encourage innovation and creation in the studio was first developed with the late English painter Peter Schmidt in 1975. It was a deck of cards called "Oblique Strategies." The decks were produced in a small printing run. On each card was a brief aphorism meant to encourage risk-taking in creation. I'll reprint a few from the 1978 edition:

Abandon normal instruments

Accept Advice

Accretion

Breathe More Deeply

Cut a Vital Connection

Discover the recipes you are using and abandon them

Don't break the silence

Go outside. Shut the door

Infinitesimal Gradations

Only one element of each kind

Reverse

Spectrum analysis

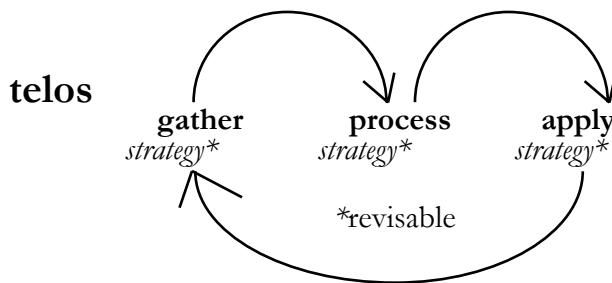
Tidy up

The various editions and a brief overview can be found at rtqe.net. When

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looking at the aphorisms, you get the sense that they are used to help the artist get out of a rut, to look at the project from different angles, to try different scales. It encourages the creator to innovate.

There's another aspect of Oblique Strategies I have found it to be useful in my work as a poet. The reason the strategies were put in a deck was because it introduces an element of randomness in the proceedings. You pick out a random card and then follow that advice. In artistic creation using randomness is called the aleatory. The Dadaists and Surrealists used this technique, cutting up texts mixing them together, then composing a poem by pulling the cut-ups out randomly. John Cage did this by putting objects in a piano's wires, then playing compositions. When James Joyce wrote his masterpiece *Ulysses*, the printer made mistakes in the prepublication drafts and Joyce kept some of them in because the text was improved by these chance occurrences. Being open to creation and innovation means being open to the gifts that randomness brings.



F. The Applying Stage

In my beginning is my end

T.S. Eliot from "The Four Quartets"

We've gone to the edge of the universe and back in this chapter to get to this final stage, yet we've never lost sight of it because we have kept our telos in mind at every moment of the recursive processes. The answer to how to apply what we've learned in the processing stage has been our focus all along. Therefore, we'll discuss this stage a little more practically than we have in the previous sections.

Generally, you can categorize the result of your processing in one of three ways. It can lead to an **artifact**. It can lead to a **belief**. Or it can lead to an **action**. An artifact is something tangible that you have produced like a report, essay, painting, or integrated circuit. A belief is a conviction that you've come to have about some aspect of reality—in other words, you decide on a depiction of reality that you'll stick with. An action is something you do with your body like conduct civil disobedience, replace the rotors on your brakes, or ask someone to marry you.

For each of the results there are three considerations we will discuss: **when** is it time to apply; **how** or, **in what form** will you apply, and what is your **quality control** in applying.

1. When?

When you're in college and using critical thinking to complete assignments, you are essentially turning in artifacts. The answer to the question "when" is pretty obvious. The application stage is completed when you turn the assignment

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in according to the deadline.

In considering deadlines, I'll remind you of what was written over the oracle's temple in ancient Greece (you went to the oracle to hear your future). Before you entered the temple you were reminded to "Know Thyself." This is great advice when thinking about future deadlines. Are you a procrastinator? Know yourself and get an early start. Do you work best under pressure? Then put yourself under pressure with a long gathering and processing stage. If you have trouble turning your artifacts in on time, revise your strategy.

Is there a deadline for beliefs? There could be. Maybe there's an election coming up and you want to decide which candidate best serves your district or country. Maybe you are required to take an oath and want to be sure you can do so in good conscience. Often, though, beliefs develop slowly, over time, as information accumulates and is processed. But the process wouldn't have started in the first place if you didn't have the desire to believe.

Actions also emerge from the telos that has directed them. Some calls to action are indeterminate—I will get my driver's license when I am confident in my driving. Some are according to a long deadline—I am training to climb a mountain next summer. Some are immediate—I have to fix my brake system this weekend so I can drive to work on Monday.

If there is not a strict deadline, it takes strategy to determine when to present your artifact or action. I suppose that the higher the stakes of the application, the more confident you want to be that your telos will be fulfilled. On the other hand, under a tight deadline, or in an emergency, you would want to launch your action at some threshold of confidence.

If you recall Jack Kilby and the development of the integrated circuit, he spent months sketching out the physics, and design before he put it together. When he showed it to his managers and colleagues, it worked. He was confident it would for he had done enough gathering and processing to be ensured of his application. I wonder if he knew how close Robert Noyce was to making his own integrated circuits would he have made the prototype earlier?

2. In What Form?

In the brief Texas Instruments documentary about Jack Kilby, Kilby remarked that his prototype integrated circuit looked crude. He said that if he knew how groundbreaking his invention would be, he would have made it look prettier. The form of application matters.

If the artifact is required in school or industry, then it's likely that the form has been predetermined. For example, if you turn in an essay in a literature class

you are expected to cite using MLA format. If you turn an essay in a psychology class, you are expected to use APA format. Business reports ought to avoid emoticons and you shouldn't wear a tuxedo to a mud run you've been training for. It's highly unlikely that you haven't thought about "in what form" while you're processing. For example, if you are writing a short story, before you send it out to be published, you have already written it. The characters are developed, the point of view established, the plot complete. So now the question is—where do you want it published? Is it fan fiction that has a place on the internet? Is it literary fiction seeking a literary magazine? Is it science fiction? Each kind of story has a particular audience and vehicle for publication. Before you submit you should have already worked this strategy out and prepared your story in the form demanded by your market.

In what form do you manifest your belief? It depends on how important it is to you that *others* know your belief. After processing the issue, you could quietly hold onto a conviction that Ford makes the best truck, or put one of those Calvin and Hobbes stickers on your back windshield that shows Calvin doing what Tycho Brahe didn't, on a Chevy. You could join an organization that shares your belief or use that belief as the telos to producing an artifact that serves as a testimonial. Above all, that belief should manifest itself in the actions you take within that belief's purview.

Athletes think about the application of their bodies to fulfill their telos all the time, often having a mantra that repeats certain baseline actions: "eyes on the ball," "shoulders square," "look up at release."

When the action is moral, or involves interpersonal relations, it's best to remember what you've learned in the section on rhetoric and the rhetorical situation. What should be your demeanor? How formal should your speech be? Should you be sitting down or standing up? I imagine there would be intense strategy involved if you were to ask your significant other for their hand in marriage. Essentially, how you apply the result of your processing is akin to the delivery stage of rhetoric.

3. Quality Control

I don't mean to diminish the behavior of critical thinking by using a term from manufacturing to contextualize its application but it is, I think, a good way to think about what we've done when we've finished a cycle of critical thinking. *Every* stage in critical should be undergoing quality control. Each strategy in each stage is subject to scrutiny. The application stage is no different and subject to the same kind of search for efficiencies.

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If you look at our graphic for critical thinking you'll notice that sometimes the application stage leads right back to the gathering stage. In that case, we gather the *entire process we have gone through* in order to process it. If the telos is unfulfilled at application, the entire process is examined and processed in order to make sure the telos is fulfilled the next time. When we were processing the logical problem from *Lady or the Tiger?*, we set up the truth table knowing in advance the first test sentence probably wouldn't work. We were making sure the process worked.

Many applications are provisional and are run to check the process, to generate information to use in the next go around. I encourage my students to turn in work before the deadline so they can get my, and their other teachers', feedback on assignments. Otherwise, quality control after the application is entirely out of their hands, ultimately finding its way to the gradebook.

In general, having another set of eyes will help you produce quality work. Someone else may see something that you aren't seeing. Seek out colleagues and mentors to you improve your strategies.

How do we conduct quality control on a belief? This is where the critical thinker encounters the most resistance. Once a proposition passes into belief it tends to stay there unless there is compelling evidence that the belief is misguided, and that still often isn't enough. Why not? Because the belief becomes part of ideology. That is why keeping an open and curious mind is so essential to critical thinking.

Conducting quality control on an action depends on the context of the action. We'll look at two different time-scales. First, imagine you find yourself in one of the moral quandaries we generated at the beginning of the Critical Thinking chapter: *You need your job to support your sick child and discover your employer is engaged in illegal, but not very damaging, activity, should you report her?* In the gathering stage you got some evidence of what she was doing. You researched your own culpability in not reporting her. You processed it long and hard and decided to help your boss out of the moral hazard. You talk to your boss in such a way that you demonstrate you know what is going on but, rhetorically, make it seem as if your assumption is that she doesn't know what she's doing is illegal. So you give her an out. Maybe your boss fires you anyway. Maybe your boss promotes you.

In any case it will probably be a long time, if ever, that you are confronted again with that kind of moral dilemma. If you are, you can take the consequences into consideration, but it's unlikely you'll ever have to. On the other hand, imagine you are a surgeon specializing in the hand. You have a thriving practice so you operate three days a week, four times each of those days. Throughout your practice you are adjusting your approach—changing your hand position, moving

lighting, buying innovative instruments. The stakes are high each operation so it's paramount that you improve your technique to improve your success rate.

“Continuous improvement”: before it was trite, was true. Manufacturing used to put its quality control resources at the end of the production process; it is by now a commonplace that improving the quality of your process takes place at every stage, at every moment. As we've said before, critical thinking is no different. And though critical thinking can be itself a recursive process, there is something especially fulfilling and exciting when you put effort in gathering and processing in order to achieve your telos, and then, when the time is right, you send the result of your labors out into the world.

4. The Applying Stage: What We Learned

- a. In the beginning is my end.
- b. Critical thinking generally results in an artifact, belief, or action.
- c. When to apply your results is a critical issue.
- d. How (in what form) you apply your results is a critical issue.
- e. How you conduct quality control on your application is a critical issue.
- f. Often the “when” is determined by a deadline.
- g. “Know Thyself” when it comes to deadlines.
- h. There's a wide range of appropriate times to apply beliefs.
- i. Follow the form when it's given.
- j. Know the context for your application.
- k. What can you do with a belief?
- l. Watch out for ideology.
- m. Remember the rhetorical situation.
- n. I use an unfortunate manufacturing term.
- o. Sometimes the entire critical thinking behavior gets passed to the gathering stage to be revised.
- p. Seek another set of eyes, or a mentor for your projects.
- q. Strive for continuous improvement, though not all situations require it.
- r. It's good to finish something.