The ability to think clearly, logically and critically is a learned process. Advancing these cognitive abilities is greatly facilitated when the individual that is meant to develop these abilities is an informed, active and willing participant in the process. As a first step in developing the critical thinking skills in you, an aspiring biologist, this handbook introduces you to the Scientific Method and the foundations in Critical Thinking. The final section of this introduces you to the breadth of research that is being actively engaged in within the Biology Department. Many of you may join a laboratory and hone your critical thinking skills while you contribute to the process of scientific discovery.

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II. Introduction

Panel A  Nestled in the heart of the campus, Shoemaker Hall is home to the Biology Department

Panel B  This aerial view shows the layout, buildings and outdoor research plots at the Biological Field Station. The Field Station is located about 20 minutes by car northeast of the main campus.

WELCOME to the BIOLOGY DEPARTMENT

The Biology Department has instructional and research faculty committed to developing your academic capabilities and your ability to think effectively. With facilities housed in Shoemaker Hall (panel A) and a Biology Field Station (panel B), Biology faculty members engage students in both classroom and laboratory settings. The goals of the faculty include not only wanting students to learn about the biological sciences but, just as importantly, the faculty wants students to learn to think critically in all aspects of their lives.

This handbook is meant to help you get a leg up on thinking both scientifically and critically. It should be emphasized that the success of the handbook and the faculty requires your personal commitment and investment in the processes of learning HOW to learn and improving your critical thinking skills set.
III. The SCIENTIFIC METHOD

directing the methodical, logical investigation of our natural world

History of the Scientific Method

Initiated by early inquisitors of the natural world, including Copernicus (1473-1543) and Galileo (1564-1642), the scientific method was formalized by the British aristocrat Francis Bacon (1561-1626). The scientific method allowed scientists around the world the structure needed to allow their research to be open, unbiased, and testable. After more than 400 years of scientific discovery, researchers still strive to design their studies using the scientific method.

General description of the SCIENTIFIC METHOD

A. OBSERVATION
B. QUESTION
C. HYPOTHESIS
D. PREDICTION
E. EXPERIMENT
F. ANALYSIS
G. CONCLUSION
H. ITERATION

Conclusion  Supports the Hypothesis or Supports the Hypothesis of No Effect (NULL Hypothesis) or is Inconclusive
Iteration  repeated correction and revision of the steps as data is developed and analyzed and how logic dictates

Scientific Method(s)  variations amongst the Scientific disciplines

It should be noted that, while modern science is centered around hypothesis-driven design, the enormous breadth of scientific questions being asked today requires significant variability in the experimental design. For example, in the AIDS studies described below, the number of available and willing study subjects and resources that are available allow for rigorously controlled experimental designs. This allows for confident conclusions about even small differences in drug treatment. Compare that with studies that question the migration patterns of monarch butterflies. Their question is still addressed with a hypothesis (e.g. monarch butterflies migrate from the US and Canada to overwinter in Mexico). Their ability to manipulate the variables, conditions and controls, however, is comparatively restricted.
The panels below show two examples of how the *Scientific Method* can be employed to address problems in both scientific and non-scientific settings.

### Beating Alabama (2014 & 2015)

**OBSERVATIONS:**
1. Alabama usually only scores ~14-21 points/game
2. Alabama’s run defense is ranked in the top 5
3. Ole Miss has QB’s with strong, accurate arms
4. Ole Miss has several tall, fast receivers

**QUESTION:**
How can we beat Alabama?

**NULL HYPOTHESIS:**
There will be no difference between an offensive strategy and a defensive strategy.

**ALTERNATIVE HYPOTHESIS:**
Ole Miss should deploy a pass-oriented offense.

**PREDICTION:**
If Ole Miss deploys an up-tempo, pass-oriented offense then this will allow for ≥ 3 offensive touchdowns, which will outscore Alabama’s offensive production

**EXPERIMENT (the game):**

*Variables*
1. Pass vs. Run
2. Up-tempo vs. Huddle

*Measurements*
1. Number of plays
2. Number of passes
3. Number of completions
4. Number of huddles
5. Yards of offense
6. Points scored

**CONCLUSION:**
Reject Null Hypothesis and Support Alternative Hypothesis

2014  Three Bo Wallace passing touchdowns and one field goal led to Ole Miss defeating Alabama 23-17

2015  Three Chad Kelly passing touchdowns helped Ole Miss win a shootout 43-37

### Beating AIDS

**OBSERVATIONS:**
1. HIV is a retro virus that uses reverse transcriptase to replicate its genome
2. Reverse transcriptase is error prone
3. HIV quickly develops mutations that give resistance to individual anti-viral drugs

**QUESTION:**
How can we treat AIDS more effectively?

**NULL HYPOTHESIS:**
There will be no difference in effectiveness between using a single drug or a combination of drugs to treat the symptoms of AIDS.

**ALTERNATIVE HYPOTHESIS:**
Using a combination of drugs will have an effect on treating the symptoms of AIDS.

**PREDICTION:**
If we use a combination of ≥ 3 different drugs then the combination will be effective even if the virus develops resistance to an individual drug

**EXPERIMENT:**

*Variables*
1. Same drug class vs. different classes
2. Early infection vs. late infection

*Measurements*
1. Number of virus particles
2. Number of CD4+ cells
3. Number of macrophages
4. Number of infected cells
5. Rate of single-drug resistance
6. Rate of multi-drug resistance

**CONCLUSION:**
Reject Null Hypothesis and Support Alternative Hypothesis Combination Therapy using multiple drug classes to overcome single drug resistance has been a proven AIDS therapy
IV. CRITICAL THINKING

What is ‘Critical Thinking’?
Critical thinking is the conscious, deliberate and purposeful act of analyzing and evaluating your thoughts with the intent of improving how you think when challenged with difficult questions or options.

YOU are the key component in developing your ‘critical thinking’

Character Traits of the Critical Thinker
- Self-DIRECTED
- Self-DISCIPLINED
- Self-MONITORED
- Self-CORRECTIVE

Why ‘Critical Thinking’?
Left unchecked, our thinking is prone to becoming biased, distorted and uninformed. The quality of our lives and livelihoods is largely dependent on our ability to think clearly, analytically and decisively.

Investing your time and efforts into learning and mastering the discipline of critical thinking will prepare you for success in your future.

Better Grades
Higher Post-Grad Test Scores
Promotes Professional Development
Facilitates making Life’s Decisions

Engaging in METACOGNITION
(THINKING about THINKING)

A key element of critical thinking is metacognition, the purposeful and conscious self-monitoring of learning. Metacognition and critical thinking are learned skills that will require the commitment of your time and energy before these skills are mastered.

LEVELS of KNOWLEDGE
The Levels of KNOWLEDGE are classically described in the Bloom’s Taxonomy. Students are encouraged to look up and spend some time thinking about the different levels of knowledge in Bloom’s Taxonomy. For our purposes, a simplified and condensed version with three sequential Levels of Knowledge is presented.

<table>
<thead>
<tr>
<th>1st LEVEL FACTUAL</th>
<th>2nd Level APPLICATION</th>
<th>3rd Level CONCEPTUAL</th>
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<tr>
<td>Building a Foundation of Knowledge</td>
<td>Using the Foundational Knowledge</td>
<td>Integrate, Dissect, Evaluate Knowledge</td>
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Practicing ‘Critical Thinking’

When training and conditioning their athletes, coaches are fond of reminding them that ‘fast or slow, every player can get faster; weak or strong, every player can get stronger’. It is important for the developing Critical Thinker to believe that there is not a limit to their learning. To get ‘faster and stronger’ in their ability to Think Critically, the individual must commit to practicing Critical Thinking.

During your lectures and laboratory sessions, your instructors routinely incorporate challenges and analyses that will require you to utilize Critical Thinking. Likewise, as you advance into the upper division biology courses your instructors will provide opportunities to practice Critical Thinking by presenting questions that require a student to evaluate the question, recall pertinent information, analyze graphs and data and respond in a clear, concise and persuasive manner.

The rate, depth and breadth of your developing Critical Thinking skills can be greatly facilitated by self-practicing these skills and approaches when responding to questions and challenges that arise in your daily life. As opportunities arise, take some time and think critically about how you are thinking.

Structures to Facilitate Self-Directed Critical Thinking

“Okay, I want to practice... how do I get started?”

There are numerous options but three widely used approaches include learning how to:
(1) generate Concept Maps;
(2) perform Argument Mapping and;
(3) learn how to apply John Lett’s Field Guide to Critical Thinking.

Concept Maps are diagrams that record the direct and indirect relationships between different concepts or factors. See examples below.

Argument Maps provide tangible frameworks that promote thinking about lines of evidence that support or refute an idea or a statement in a comprehensive and open-minded manner. See examples below.

For both forms of mapping, having a tangible, written record, allows the mapper to have clearer recall of his/her thinking and for their train of thought to be redirected or reconsidered.

John Lett’s Field Guide evaluates and validates if specific statements are true or false by subjecting them to six specific questions. The guide is shown below.
Creating a **CONCEPT MAP**

There are a myriad of different forms of *Concept Maps* but most begin with a main idea or concept and then build around that central point with factors that lead into that concept (connecting with an arrow pointing toward the main concept) and with factors that arise from the central point (connecting with an arrow pointing away from the main concept).

**CONCEPT MAP:** The relationship of other macromolecules and biochemical pathways to DNA
**Generating an ARGUMENT MAP**

While there are numerous variations, *Argument Maps* generally include color-coded circles or boxes that circumscribe the statement or concept in question, observations that support or refute the statement and evidence that support or deny the observations. The color-coding might include:

<table>
<thead>
<tr>
<th>Color</th>
<th>Description</th>
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<tbody>
<tr>
<td>BLACK Box</td>
<td>encircles the statement that is under debate</td>
</tr>
<tr>
<td>GREEN Box</td>
<td>contains lines of evidence that would provide support for the primary statement often referred to as ‘because’ boxes</td>
</tr>
<tr>
<td></td>
<td><em>(Statement X is more likely because of Evidence A)</em></td>
</tr>
<tr>
<td></td>
<td>second level boxes support, refute or qualify evidence in first level boxes</td>
</tr>
<tr>
<td>RED Box</td>
<td>contains lines of evidence that would contradict the primary statement often referred to as ‘but’ boxes</td>
</tr>
<tr>
<td></td>
<td><em>(Statement X may be valid but is not supported by Evidence B)</em></td>
</tr>
<tr>
<td></td>
<td>second level boxes support, refute or qualify evidence in first level boxes</td>
</tr>
<tr>
<td>ORANGE Box</td>
<td>potentially impactful info that is not yet clearly supportive or contradictory Information that tempers the strength of a GREEN or a RED observation Often referred to as ‘however’ boxes</td>
</tr>
<tr>
<td></td>
<td><em>(e.g. Evidence B may contradict Statement X however Observation M may eliminate or minimize Evidence B)</em></td>
</tr>
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</table>

Below is an example *Argument Map* to evaluate the statement that:

*Argument Maps help clarify one’s thinking*
Hypothetical Example: **Inside the mind of John Snow**

In the mid-1800’s, the industrial revolution was in full swing in Europe. Needing manpower, industry lured a multitude of workers to the industrial centers. The resident population in London rose from 1 million to 6.8 million during the 19th century. Like other European centers, the water and sewage treatment facilities were overburdened. This led to human waste being dumped into the Thames river, a primary source of drinking water in London, and into neighborhood cess pools in close proximity to public wells, a second source of drinking water. As anticipated, London’s water supplies became contaminated. One specific bacterium, *Vibrio cholera*, established an insidious cycle in humans where drinking water with heavy bacterial loads allowed some of the bacteria to survive the acidic environment of the stomach and adhere to the wall of the intestine. Here the bacteria would proliferate at high rates and secrete a toxin that induced the secretion, rather than the absorption, of fluid across the intestinal wall. This produced a watery, bacteria-laden diarrhea. This waste was dumped into the river or neighborhood cess pools and restocked the waters with more bacteria.

At that time, the widely accepted medical explanation for the cholera epidemics that swept through the city was *miasmatism*, a theory that held that ‘foul air’ contained poisons and individuals that inhaled the poisonous air were susceptible to developing cholera. An alternative explanation was put forth by John Snow. Snow hypothesized that cholera was transmitted between individuals by a cyclical route of fecal-oral transmission. By developing and employing novel epidemiologic techniques, Snow went on to show that fecal contamination of the local groundwater allowed *Vibrio cholera* into well water to be ingested by those using that well.

If John Snow had used Argument Mapping to facilitate and organize his assessment of the transmission of *Vibrio cholera* in London during the 1850’s, it might have looked something like the map shown below:
John Lett’s Field Guide to Critical Thinking

Beyond Argument Mapping, a commonly applied guide to facilitate the critical analysis of statements was developed by John Lett (A field guide to critical thinking. Skeptical Inquirer 14(2): 153-160, 1990). This guide provides a framework of six steps to evaluate a statement, explanation, conclusion or prediction. If your analysis of a statement indicates all six steps are positive the statement is considered ‘true’. This holds until other evidence comes into play that results in a negative response to one or more of the six questions. It also should be emphasized that a negative response disallows a definitive ‘true’ stamp but in later analyses the statement may be found to be true and change your assessment.

The six steps include:

1. Is the claim falsifiable?
   For any explanation to be considered science, it must be falsifiable (i.e. capable of being proven FALSE). It must be possible to obtain some evidence that would falsify the claim.

2. Is it logical?
   All conclusions or predictions drawn from an explanation must be logical.

3. Is it comprehensive?
   Does the explanation account for all of the available evidence? If not, then how can it
possibly be true? This means you cannot pick and choose among the available evidence and select only those items that support your explanation. To be a viable explanation, all the available evidence must be explained.

<table>
<thead>
<tr>
<th>4. Has everyone been honest</th>
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<tr>
<td>Anybody offering an explanation has an obligation to faithfully weigh all the evidence and reach a rational conclusion. You always must be on guard of self-deception, and you must be willing to abandon any explanation if the evidence contradicts it. Science makes progress when falsified explanations are abandoned and replaced with new explanations that incorporates all the valid evidence.</td>
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<th>5. Is it replicable?</th>
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<tr>
<td>Any evidence offered in support of an explanation must be capable of being obtained independently and confirmed by someone else. If observations and statements cannot be confirmed independently, then the original evidence becomes suspect, and so does the explanation it supported.</td>
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<tr>
<td><strong>6. Is it sufficient?</strong></td>
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<td>------------------------</td>
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<tr>
<td>Is the evidence offered sufficient to support the truth of the explanation? The belief we place in an explanation must remain proportionate to the amount of credible evidence that has been accumulated in its support. Remember the burden of proof rests on the person putting forth the statement, and the more extraordinary the claim, the more solid the evidence required to support it. Further, the absence of falsifying evidence is not the same as the presence of evidence that confirms a claim or explanation.</td>
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<tr>
<th><strong>Conclusion</strong></th>
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<tr>
<td>If an explanation or claim passes on all six tests, then it is justifiably considered to be true. Of course, this does not provide a guarantee of truth, but it means you have a good basis for believing the statement. If an explanation fails one of the six rules, then it should be rejected or at least treated with great skepticism. If you consistently utilize these six rules you will become a skeptical thinker, accepting or rejecting an explanation strictly on the merit of the evidence.</td>
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Critical Thinking Works in Everyday Life

While most of the Critical Thinking development you experience through the Biology Department will be centered around scientific issues, a central benefit from developing your skills at Critical Thinking is that the same principles used to analyze scientific data can be used to make common, everyday decisions.

Companies and advertisers often rely on a lack of critical thinking to sell their products. When an advertiser makes a claim, summon your Critical Thinking skills and evaluate:

- Is it logical?
- Is it comprehensive?
- Has everyone been honest?

Below are some common examples of advertising claims:

A credit card company is offering cash back on purchases:
- The cash-back may only be available on select purchases, at select stores, or for a short period of time
- Credit cards that offer cash back often have higher interest rates, so if you carry a balance on the card the amount of cash back won't cover the amount you pay in interest

A car insurance company offers the lowest rates around:
- Most of these companies are able to offer such low rates because they never pay out in the case of an accident
- Some companies even hire lawyers to defend the opposing side to avoid paying a claim

A fruit juice is advertised as “probiotic”:
- The data on how, or even if, probiotics aid human health is unclear
- Many probiotic products only have one type of bacterial culture, while current data suggests that a mixture of different organisms is needed for a probiotic effect

A breathmint is claiming that it is “calorie-free”:
- Government standards dictate that if a given reference amount of a product is less than 5 calories, they may label themselves as “calorie-free”
- Many breathmints call themselves “calorie-free” despite being made almost entirely of sugar

A vitamin claims to be certified by a testing agency:
- These testing agencies are not associated with the Food and Drug Administration and therefore do not make claims about safety or efficacy, only that the advertised product is there at the advertised amounts
- These agencies often do not test products from the shelves but instead samples sent directly from the company
What is a typical pattern of progression in 'Critical Thinking'?

The rate of progress is dependent upon a number of factors. These factors range from the student’s knowledge base in and around the subject to their diligence in practicing critical thinking to their trust in the process of critical thinking. While the rates of progress vary substantially, there are distinct levels of critical thinking development as it pertains to the individual’s commitment to practicing critical thinking skills. These levels include:

1. **unreflective** thinker: unaware of learned thinking
2. **challenged** thinker: aware of thinking deficits
3. **beginning** thinker: trying to improve thinking process but not practicing
4. **practicing** thinker: appreciates the need for practicing thinking skills
5. **advanced** thinker: systematically practices thinking skills
6. **master** thinker: solid thinking habits are second nature

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**Critical Thinking requires these Intellectual Character Traits**

- Intellectual humility
- Intellectual autonomy
- Intellectual integrity
- Intellectual courage
- Intellectual perseverance
- Intellectual curiosity
- Confidence in reason
- Fairmindedness
### V. Research: the NEXT Step

**Research in Biology? We have you covered from B to Z**

As you acquire and hone your scientific and critical thinking skills, you may want to apply your new skills doing research under the guidance of one of our faculty members. From Susan Balenger, Ph.D. to Peter Zee, Ph.D., the research interests of the Biology Department faculty are remarkably diverse and utilize a wide array of models to explore a myriad of hypotheses. Examples of the diversity our faculty member's laboratories are shown in the figure below. **Importantly, the laboratory is an OUTSTANDING environment to engage in active learning, utilize existing critical thinking skills and develop additional critical thinking skills.**

For a full list of biological research programs please see: biology.olemiss.edu/research/

<table>
<thead>
<tr>
<th>Dr. Susan Balenger</th>
<th>Dr. Steve Brewer</th>
<th>Dr. Richard Buchholz</th>
<th>Dr. Patrick Curtis</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>-host-pathogen interactions in bluebirds and crickets</strong></td>
<td><strong>-fire, competition and plant biodiversity</strong></td>
<td><strong>-elongated snoods play a key role in turkey mate selection</strong></td>
<td><strong>-cell signaling in prokaryotes</strong></td>
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</tbody>
</table>
Dr. Wayne Grey  
-novel approaches to generating viral vaccines

Dr. Mika Jekabsons  
-mitochondrial control of metabolism and apoptosis  
(=mitochondria (red) in cultured neurons (green))

Dr. Bradley Jones  
-neural development in fruit fly larvae

Dr. Chris Leary  
-neural/endocrine regulation of behavior

Dr. Sarah Liljegren  
-cell signaling control of plant development

Dr. Glenn Parsons  
-skates, rays & SHARKS

Dr. Peter Zee, Ph.D.  
-experimental evolution using microbes