Organizing Scientific Thinking Using the QuALMRI Framework

Adapted from Kevin Ochsner, based on a scheme devised by Steve Kosslyn.

This handout outlines a structured process for generating, asking, evaluating, and answering scientific questions. This process, denoted by the acronym QuALMRI, can be used to organize and plan your own research, outline your writing about it, and help understand the research of others. QuALMRI stands for: **Qu**estion, **A**lternative hypotheses, **L**ogic & design, **M**ethod, **R**esults, and **I**nferences. The QuALMRI format can help you make clear what the *question* is that you are asking, and help you to relate it directly to some means of testing it. It is also a useful structure to keep in mind when you are interpreting someone else's research.

This handout has two parts, both of which are important to review each time you're writing up your own projects this semester (whether that be your Class Data Mini-Report, your Project Proposal, or your Final Project Writeup):

Part 1 is a detailed description of the 6 main steps of the QuALMRI process;
Part 2 is a streamlined blank template for use in outlining.

<u>Part 1: QuALMRI in Depth</u>

I. Begin with a Question

What do you want to know about? All research should be motivated by a clearly defined question or set of questions that the research seeks to address.

A. Questions can be considered at two levels:

1. <u>Diffuse</u> questions provide a "bigger-picture" motivation for research, such as, "how does a time delay affect decision making?" These questions cannot be addressed in single experiments, but rather are answered by considering patterns of data across different studies, each of which addresses a more specific question.

2. <u>Specific</u> questions are "bite size" pieces of larger, more diffuse, ones. For example, given a general interest in decision making across longer time horizons, a more specific, more *focused* question might be, "how does a time delay affect the value we place on getting a reward?" This question could be refined further by focusing more closely on examination of different lengths of delay, different sizes of reward, different types of reward (e.g., monetary vs. food vs. health vs. environmental outcomes).

B. Make clear the <u>connection</u> between diffuse and specific questions. Usually a diffuse "big picture" question is made clear at the beginning of an article, and then specific smaller questions to be addressed in individual experiments are also identified. Clarifying the connection between them is essential for mapping out the motivation behind the research. As an experimenter, this entails making clear how your specific questions relate to the more diffuse motivating issues; as a reader/evaluator of others' work, it entails extracting this information and making sure that the specific questions addressed in each experiment meaningfully relate to the "bigger picture."

C. Good questions are motivated by <u>theories</u>, and experiments addressing such questions have implications for the correctness of the theory. Just as we cannot explore a large issue in just one study, we cannot design a single experiment to test a comprehensive theory all at once. Instead, we have to test the theory bit by bit, using simple experiments that each alone address only small questions, but together have implications for the correctness of the theory as a whole. In addition, interesting questions can be posed such that their answers support only one of a number of competing theories.

D. A good question will provide one piece of converging evidence. Remember that a single specific question and an individual experiment won't provide an answer to a whole "big picture" question all at once. Although the ultimate goal may be to solve a large puzzle, the single experiment you're designing or evaluating may provide but a single piece of evidence for that puzzle. In general, a balanced approach to research involves the use of many different experimental methods and subject populations to help *converge* upon a single explanation, theory, or inference: the results of each study, when considered in isolation, may be subject to different interpretations, but when considered in concert with other supporting evidence, point towards a single conclusion. Remember, however, that it takes time to accumulate this evidence, and that it may be necessary to conduct many experiments before the larger puzzle is complete. Steady, carefully planned, and incremental research wins the race, and along with converging evidence is a particularly powerful research technique, especially when employed in the service of focused research questions.

E. Check to make sure you've got a clear question. Sometimes research is conducted without a clear question in mind; if you are having trouble figuring out exactly what question is being addressed in a paper you read or for a study you're designing, it could be that the authors (which may be you) were similarly confused (or were "fishing" or "data mining"). In such cases it is difficult to determine what the results of the experiments mean—without knowing what the question is that motivated a given experiment, we have no clear means of interpreting what the results of that experiment mean. Always remember that, "what counts as an answer depends on the question you ask." *If you're unclear about what your question is, you can't know what to count as an answer.*

NOTE: many important scientific advances have come unexpectedly and unpredictably, which may at first seem at odds with the idea that steady incremental research is a good way to proceed. Some researchers do take an exploratory approach, and test out "wild" ideas just to see what will happen. However, this does not mean that the experiments conducted to test these speculative ideas were not well planned or carefully designed for a purpose. When unexpected results are produced, one has to be open to considering their potentially novel implications, and know when and how to explore them further. Unexpected results are, in fact, a great place from which to start a *new* experiment. (Your diffuse question, or even your specific question, doesn't have to stem from an existing theory—it can also come about as a way of better understanding a surprising result from a prior study.)

II. Alternative Hypotheses

The questions addressed in particular experiments should have more than one possible answer; we do experiments to provide evidence that can rule some hypotheses out, and provide support for others.

A. There are two broad ways of presenting alternative hypotheses

1. Your/the main hypothesis could be correct or incorrect. Sometimes the alternatives may simply be that something either will or will not happen. For example, one might hypothesize that women tend to use more affective-based decision modes, while men tend to use more calculation-based modes. One alternative to this hypothesis is simply that this prediction is incorrect.

2. There are different types of alternative hypotheses, only some of which may be considered within a single experiment. In this case, your hypothesis might be one of a whole class of alternatives: For example, one might hypothesize that priming of emotional goals before a decision process could result in either higher rates of affect-based decision mode or in higher rates of goal-satisfaction-based decision mode, or in another outcome altogether.

B. Order of presenting hypotheses. In writing, you should try to spell out all the possible answers to your question and show how they relate to the issue in the following order:

1. First provide the hypothesis that you think is correct, and explain why.

2. Then present the other alternatives. Be sure to make clear how your experiment will tease apart each hypothetical, alternative outcome. The important thing is that each possible alternative bear directly on the question at hand, and that the question is posed such that its possible answers are theoretically meaningful.

III. Logic & Design
The next step is to consider the basic design of your experiment keeping in mind that the results of your experiments should support one or another alternative hypotheses. The basics of the design include:

A. Specification of dependent and independent variables: Dependent variables are what you measure (e.g., a P's choice of A over B, reaction time, willingness to pay, etc.) and independent variables are what you manipulate (e.g., the domain in a discounting problem, priming of various emotions before testing the Endowment Effect, whether participants in a reinforcement learning study are seeing gains or losses, etc.). An independent variable might include manipulation of subject groups, such as men vs. women, high vs. low maximizers, young vs. old, or psychiatric patients vs. controls. The use of special subject populations should tell you something interesting about the phenomenon you're measuring. For example, older Ps might respond with less risk seeking than young Ps, and might be more sensitive to feedback about the appropriateness of their conversational styles. Including young and old participants in the experimental design allows this hypothesis to be tested.

B. Operational definitions of variables of interest: An operational definition specifies the "operations" in your experiment that you will count as a measure of the "thing" you're interested in. So if you are interested in risk aversion, you might operationally define it based on Ps' preference for a less risky gamble over a more risky one. Or, for the same variable of risk aversion, you could measure it by asking Ps to turn over as many cards as they want, when most cards offer rewards but an occasional few come with large penalties. Or you could measure risk aversion by asking your Ps how much they would be willing to pay for a ticket to play various gambles. The way in which we measure variables becomes our definition of them within the context of our experiment. In general, you should try to measure and/or control any variable that you think might meaningful influence the outcome of your experiment(s).

C. Deductive logic statements for your question specifying how an experimental outcome will follow from particular alternative answers to your question: These statements are in the form of, "If (hypothesis X) is true, then (manipulating independent variable x should lead to result y)." One of these statements can be made in support of each alternative hypothesis.

IV. Method
After coming up with the basic design you have to specify the process by which you will run your experiment. This includes:

A. Most importantly, realization of each independent and dependent variable used in your design. This means (depending on the specifics of your experiment) stating exactly:

1. who the participants will be, how they were/will be recruited and what their demographics are (e.g., mean age, gender breakdown, and any other relevant qualities that could relate to your hypotheses).

2. what kind of stimuli or questionnaires will be used, how many, and how they relate to each experimental condition defined by your independent variables.

B. Explanation of the procedure that will be used. This includes a description of the sequence of events that occurs when participants participate in the experiment and should specify:

1. **the instructions** they are given,
2. **what they see**, when, for how long, and in what order,
3. **how data are collected**, including what Ps do to indicate their choices, and when,
4. **and finally, about how long** the entire **experimental procedure will take.**

V. Results

A. Presentation of results should be in order of importance and relevance to the initial question, and should indicate what values of your variables were found in conducting your experiment. Tables and graphs are often used to clearly present data.

B. Remember, however, that one should **write clear descriptions of the data,** whether it is presented in the text, shown in tables, figures or charts; it is never safe to assume that results speak for themselves. When writing, always keep in mind that you are trying to make sure that the relationship between the results and the initial question is kept clear. The results section is part of the larger story being told by an experiment, and it is important to make sure that the results presented are providing answers to the questions you posed in the introduction. For example, if 87% of Ps prefer the risky deck of cards to the safer one, then state that in the text, present the statistics in a table or graph (its easier to remember trends and patterns when presented visually as well as verbally) and refer readers to that graph or table in the text.

VI. Inferences

After examining the results, it should be possible to use the experimental logic to infer that one or more alternative hypotheses are supported by the data.

A. Consider first the inferences most directly implied by the results and most relevant to the questions at hand, in order of importance. If it is difficult to determine how the results lead to inferences about the questions, then either the question was poorly defined, the logic was flawed, the method was faulty, or you're tired.

B. When evaluating someone else's work or even your own, **be careful to discriminate between the inferences that the authors of the study *wish* to draw, and those that are *warranted* by the results.** Try to find flaws in the experimental design, faulty logic, flawed procedures, fuzzy questions, biased sampling of participants, etc., that limit the ability to draw meaningful inferences from the data. How do those flaws affect our ability to make inferences from the results? This guideline of looking critically at the conclusions of a study holds true even when the author of the study is you—literally zero scientific studies are entirely free from flaws or weaknesses.

C. Make suggestions as to how to fix flaws, overcome them, or follow up on them in subsequent experiments. Note that not all limitations damn a study to the scrap heap; *all* studies are limited in *some* way (remember that each study is addressing only a small piece of a larger puzzle, and so *by definition* is limited in scope) and what's most important is whether and how limitations restrict the inferences that can be drawn about the question that is of interest. If the results are confusing or can't answer the question in a reasonable way, then it may be time to start over at the drawing board. This is not necessarily BAD—as noted earlier, many important advances come unexpectedly, and in ways that suggest confusing answers to the questions that initially motivated the research. Part of the art of science lies in knowing whether a "weird" result is truly aberrant and unlikely to replicate, whether it is due to faulty experimental design, whether it means that unwarranted assumptions have been made about the phenomenon being studied, or whether it means that a particular line of research should be abandoned, and a new one devised that explicitly follows up on this new and intriguing finding.

Part 2: QuALMRI Template

I. Question

A. Diffuse, or "big picture" question:

B. The specific question(s) addressed in the research:

C. The connection between the two:

II. Alternative Hypotheses

A. Your/main hypothesis:

B. Other alternatives:

III. Logic & Design

A. Specification of dependent (DV) and independent (IV) variables:

B. Operational definitions of variables of interest:

C. Deductive logic statements for your question specifying how an experimental outcome will follow from particular alternative answers to your question:

IV. Method

A. Realization of each independent and dependent variable:

1. Participants:

2. Stimuli or questionnaires:

B. Procedure:

1. Instructions:

2. What they see, when, for how long, and in what order:

3. Data Collection:

4. Length of entire experimental procedure:

V. Results

A. Presentation of results in order of importance and relevance to initial question(s):

B. Descriptions of the data shown in tables, charts, etc., as necessary:

VI. Inferences

A. Inferences most directly implied by the results and most relevant to the questions at hand, in order of importance:

B. Discriminate between the inferences that the authors (which might be you) of the study *wish* to draw, and those that you think are *warranted* by the results, by identifying potential flaws and limitations in any stage of the experiment:

C. Suggestions as to how to fix flaws, overcome them, or follow up on them in subsequent experiments.