

Formulating Research Questions and Hypotheses

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This document explains principles for satisfactorily producing a research question or hypothesis for your PhD or MS research prospectus or other proposal. Such is part of defining the scope of your project and should first appear in the introduction section.

It is tempting to avoid the difficult work of formulating a research question or hypothesis, believing that it will be easier later when you have done more study or experiments, or that it somehow doesn't apply to your project. Instead let's do the hard work now! It will require iteration as you make improvements and refine your thinking.

1. Not everything is of equal importance

The [Pareto principle](#), sometimes called the 80/20 rule, teaches that around 80% of the outcomes are caused by around 20% of the inputs. In other words, some factors are much more important than others in explaining why or how something happens. There are underlying physical and mathematical reasons for this basic idea, even if it is not precisely observed for all systems of interest.

The general principle that not everything is of equal importance is taught by God in scripture, as are spiritual questions and hypotheses. Two examples:

For behold, I say unto you there be many things to come; and behold, there is one thing which is of **more importance** than they all—for behold, the time is not far distant that the Redeemer liveth and cometh among his people. Behold, I do not say that he will come among us at the time of his dwelling in his mortal tabernacle; for behold, the Spirit hath not said unto me that this should be the case. Now as to this thing I do not know; but **this much I do know**, that the Lord God hath power to do all things which are according to his word. (Book of Mormon, Alma 7:7-8)

And now abideth faith, hope, charity, these three; but the **greatest of these** is charity. (Bible, 1 Corinthians 13:13)

2. Careful thinking can guide you to the most important things

In formulating your project scope, merely proposing to work on problem X or study subject Y is not sufficient. For one thing, there is no natural stopping point for such a project—you could spend literally your whole life studying one topic. Instead, the scope should be narrow and specific, so it is clear that the project can be accomplished in a realistic amount of time and obvious when it should end.

Secondly, formulating your scope through research questions or a hypothesis will force you to think in advance about what is most important. It will cause you to bring to bear on your problem all the accumulated human knowledge that you can. By doing this difficult thinking first, your future efforts

will be more focused and therefore more productive with the limited time you have. In other words, you will be able to design better experiments or theoretical models.

Even for an engineering project whose goal is to build a tool (either an apparatus or a computer-based model) to perform some practical function, the project can be driven by hypotheses and research questions. For the most part, your audience does not care about the tool itself but rather what insight the tool makes possible. Furthermore, even if the intended functionality of the tool is not fully realized over the course of your degree (i.e. it doesn't work as well as you hoped), a hypothesis- or question-driven project will more likely advance scientific knowledge (i.e. allow you to graduate still).

You need not limit your project scope to just one research question, though it is more common to limit to one hypothesis. Whether to formulate a research question (or questions) or a hypothesis often depends on how mature is the understanding of your topic.

A research question...

- often precedes a hypothesis.
- is more exploratory of a topic and suggests a path for finding out more.
- asks *who*, *what*, *where*, *how*, or *why*.
- wonders about a previously unobserved but plausible trend.
- seeks to quantify the causation or correlation between certain variables.

A hypothesis...

- follows sufficient observations that we have begun to form concrete connections.
- proposes an underlying physical or conceptual *mechanism* to explain prior observations.
- is designed to confirm what we think we know.
- predicts a clear link between variables that can be *tested*.

For additional perspectives see

<https://en.wikipedia.org/wiki/Hypothesis>

<https://www.servicescape.com/blog/how-does-a-hypothesis-differ-from-a-research-question>

<https://libguides.centenaryuniversity.edu/c.php?g=1452926&p=10801336>

3. You need to iterate and get specific

We first conceptualize a project in general terms, but we need to iteratively make the scope more specific until it is suitable for the amount of effort we can devote to the project. We will illustrate the iterative process of developing a research question or hypothesis for a project to *improve manufacturing through artificial intelligence*. An example research question could be

How does the implementation of artificial intelligence in manufacturing enhance efficiency?

or perhaps

What is the most effective way to enhance manufacturing efficiency with artificial intelligence?

Such questions express curiosity about the topic and helpfully explore a connection between two variables. The problem is that each question is entirely too general for a finite project or to make a meaningful scientific conclusion. To strengthen them we must do some thinking and planning and make them more specific:

What increase in energy efficiency in curing carbon fiber composite parts is possible by employing artificial intelligence strategy X?

or perhaps

To reduce waste in building carbon fiber composite turbine blades, which is the better artificial intelligence optimization strategy: X or Y?

Now let's turn to possible hypotheses for this project. An initial hypothesis could be:

My hypothesis is that integration of artificial intelligence in manufacturing improves efficiency.

Again, it is not narrow enough for a finite project as it doesn't specify which kind of manufacturing, efficiency, or artificial intelligence, each of which are broad fields of inquiry. Additionally, this hypothesis is scientifically boring. It is effectively saying

My hypothesis is that my project will succeed.

which excites no one in your audience, did not require any careful thinking about the problem, and does not contain any scientific insight.

In addition to making the hypothesis narrower, it would be better to encode an underlying mechanism of action into it:

My hypothesis is that the integration of artificial intelligence strategy X in manufacturing material Y substantially increases energy efficiency by the mechanism of Z.

(with X, Y, and Z specified).

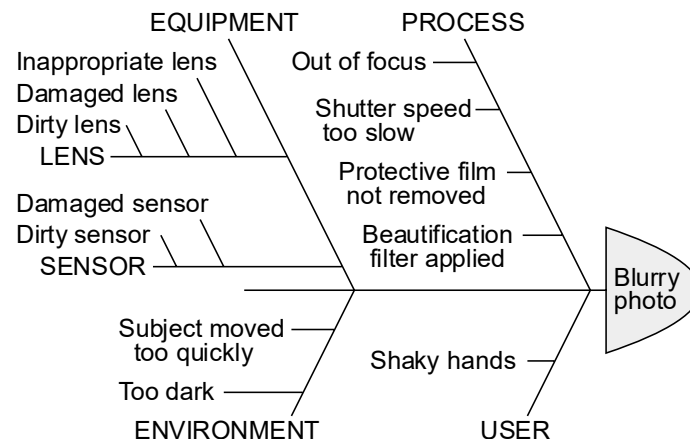
Once we have a suitable research question or hypothesis in hand, we can then begin to formulate the research plan that will enable the question to be answered or the hypothesis to be tested. Indeed, a realistic research plan is much easier to conceive because the scope of needed variables or observations is now much reduced.

4. Root cause analysis can help in developing hypotheses

In the field of quality management, [root cause analysis](#) is used to discover the cause of defects, accidents, or other failures so they can be remedied. Like formulating a hypothesis, this kind of analysis seeks to postulate all possible mechanisms and then to discover which was or is the most influential. Thus, we can borrow ideas from this field in trying to formulate hypotheses.

Japanese researcher Kaoru Ishikawa in the 1960s promoted a technique now known as a fishbone or Ishikawa diagram in which a single observed defect is conceptually connected to categorical causes, in turn connected to foundational or root causes. Below is shown an [example from Wikipedia](#) in

which the defect is a blurry photo taken by a camera (the head of the fish). The ribs of the fish are the main categories that could contribute to the failure, with smaller bones indicating root causes within each category. Please take a few minutes to consider all the brainstorming, analysis of the process, and other thinking that was required to produce this diagram.



[Ishikawa fishbone diagram](#) for possible root causes of a blurry photo.

You may benefit from producing a fishbone diagram for one or more aspects of your project, for instance to discover how two variables might be connected or, later, to debug an experiment, material, or computer code not functioning as intended. You can see in the above example that producing a suitably comprehensive diagram requires **deep knowledge** of the process or device so that a potentially critical cause is not overlooked. How does an individual or group get this deep knowledge? Through deep effort!

Each root cause listed on the fishbone diagram is the basis for a hypothesis in parallel with other hypotheses. At the outset of the analysis, the most important root cause or causes are only suspected, and each hypothesis must be verified or instead eliminated from consideration by subsequent observation. As Sherlock Holmes said, "...when you have eliminated the impossible, whatever remains, however improbable, must be the truth." (Sir Arthur Conan Doyle, *The Sign of the Four*). Like a detective solving a mystery, you can arrive at truth through first enumerating all logical possibilities and then eliminating false possibilities while examining data.



Still from the film "Sherlock Holmes" (1922) – copyright free