Introduction to Quantitative Research Methods

II2202: Research Methodology and Scientific Writing 2015

Mark T. Smith
KTH: Swedish Royal Institute of Technology
School of Information and Communication Technology
msmith@kth.se

Quantitative Research Methods

- *Quantitative* methods are those that deal with measurable data.

It is data that is based on numbers.

- It has an *amount* that can be directly measured.
- The amount is with respect to some known *units* of measurement.
- The units are known so *comparisons* of measurements are possible.
- The comparisons are *numerically* based.
- *Results* are based and judged on such data comparisons.

- Quantitative methods are used in technical fields, such as in science and engineering and in business such as finance and marketing.

- Using quantitative methods properly are key to your success in these areas!

Quantitative Methods and Goals

We will talk about:

- The ROLE of data in a scientific study. What it really is for. It is far more important than you may think.
- PLANNING to get the data you need. What kind of data, and how much is enough. These are specifications for the study or project.
- How to MEASURE data. How to obtain the data you need.
- How to express the SIGNIFICANCE of your data. Showing what your data means.
- You should be able to exercise these skills as an independent scientist, employee, entrepreneur or consultant.

Quantitative and Qualitative methods

What's the difference?

- *Qualitative* methods deal with data that are not numbers.
- Broad things like opinion, choice or human experience.
- It is not that one is better than the other! You choose a method based on the study you are doing.
- You should choose the right study method that best fits the problem you are trying to solve.
- References on scientific method often compare Quantitative and Qualitative methods, but the comparison can get abstract.

Differences

Quantitative:

- **Numbers**
- **Researcher’s actions**
- **Theory testing**
- **Numerical based analysis**
- **Structured**

Qualitative:

- **Words**
- **Participant’s opinions**
- **Theory generation**
- **Process based analysis**
- **Unstructured**

Differences

Quantitative:

- Explanation
- Prediction
- “Hard” data (measurements)
- Objective result
- Closed (laboratory) environment

Qualitative:

- Understanding
- Interpretation
- “Soft” data (diverse and rich)
- Subjective interpretation
- Open (natural) environment

Overall Design for *Quantitative* Research

- Drivers that influence or guide research directions
- Research methods, strategies and design
  - Experiments, case studies, surveys
- Data collection technique
  - Measurements, questionnaires, case studies
- Data Analysis processes and procedures
  - Statistical methods and Data Science
- Quality Assurance
  - Validity, ethics, dependability, reproducibility, transferability
- Presentation of results
  - Written records, publications, demonstrations

Overall Design for *Qualitative* Research

- Drivers that influence or guide research directions
- Research methods, strategies and design
  - Ethnography, case studies, surveys, action research
- Data collection technique
  - Survey, case studies, observation, interview
- Data Analysis processes and procedures
  - Statistical methods and Data Science
- Quality Assurance
  - Validity, ethics, dependability, reproducibility, transferability
- Presentation of results
  - Written records, publications, demonstrations

The ROLE of data, or what data is for (a possible quantitative example from real life)

Suppose you are working for a company that designs a RFID based car parking payment system. *You* have to design:

- A system where customers pay for their parking time at a machine using a RFID tag.
- The RFID tag also is used to activate a gate that lets them leave the parking area.

Specifications:

- The RFID tag MUST be able to activate the gate when held <u>4cm or less</u> from the gate reader.
- The RFID tag MUST be read within <u>0.5 seconds</u> when held 4cm or less from the gate reader.

Note the reliance on numeric parameters.

Product Rollout!
and the boss asks “Does your RFID design work??”

Which of these answers would you be able to give to your boss?

1. “Oh wow! Who knows?”

2. “Well…..   it works *most of the time*.”

3. “If you hold the *tag steady and close enough*, it should be OK.”

4. “When the tag is held between 0 cm and 4 cm of the reader’s antenna, the gate will open within 0.5 seconds in 99% of attempts.

Let the Data Speak!

The whole point of data is to *quantitatively* show the value of something.

- ***Explain*** how well something works or meets specs with minimal ambiguity.
- Accurately ***predict*** how well something can or will work.
- Allow people to ***verify*** your work by re-doing it.
- ***Resolve*** selection criteria. Which solution is better based on what?

More Reasons to Let the Data Speak

- Estimate the value of a new idea quickly and clearly.
- Establish your credibility. That you know what you are talking about.
- To teach. To pass on knowledge and facts to others.
- To communicate in a way that others can understand.
- Remove useless elements from technical decisions, for example egos.

Two approaches to experiment design: Deduction and Induction

Deduction:

- In this type of study, you start with a hypothesis based on known facts, physical laws or theory.
- You then seek to confirm or reject your hypothesis based on the experiments you perform.
- This is called an approach based on *Deduction*.

1: Theory -> 2: Hypothesis -> 3: Observation -> 4: Accept or Reject

Two approaches to experiment design : Deduction and Induction

Induction:

- In this type of study, you have no existing theory, laws or facts you can go on. You can't form a hypothesis based on those.
- So instead, you perform experiments and observe the results.
- The observed results hopefully suggest a repeatable pattern or repeatable outcomes.
- Based on the pattern or outcomes, a "tentative hypothesis" is formed.
- The tentative hypothesis forms the basis of a new theory.
- I often call is a "what if…" study.

1: Observation -> 2: Outcomes -> 3: Tentative Hypothesis -> 4: Theory

Deduction and Induction
Which is better?

- It depends on the problem you are trying to solve. Your *problem statement*.
- If your problem statement is based on known theory, facts or physical laws, then you can take a deductive approach.
- If the problem statement is not based on such theory or fact, ie because they don't yet exist, then you take an inductive approach.
- Neither approach is perfect. Although a deductive approach allows for a result to be "proved", it is only proved in the context of the rules and laws. There is no room to deviate.
- The inductive approach does give room to deviate, but no actual proof of the outcome (the resulting theory) is immediately possible. The tentative hypothesis stays tentative until the theory is proven.

Ingredients of a quantitative study

- No matter if the study is deductive or inductive, we can generalize the steps that make up a good repeatable study.

- Problem Statement
- Literature Study
- Experiment design
- Data collection
- Data Analysis
- Study Conclusions
- References

1. Problem Statement

- What is the problem or question that you are trying to solve?
- <u>You need to make this very clear at the start of your study.</u>
- It serves to define the <u>scope</u> and <u>purpose</u> of your study.
- It also serves to give <u>specifications</u> that define your goals.
- Without it, it is very hard to form a hypothesis in a deductive approach or experiments in an inductive approach.
- Without it, it is very hard to judge your results. Nobody will know what you are talking about.
- Without it your study has no bounds. If you don't know where you are going, how will you know when you get there?

2. Literature Study

- This is a survey of the current *State of the Art.* What do people already know about the problem you are trying to solve.

- "Knowledge is power". The literature study gives you that power. Any published knowledge base. Journals, books, conferences, etc.

- You know what has already been done and the outcomes.
- You won't repeat the mistakes others have made.
- You know the challenges, successes and failures that others have identified and experienced.
- You can use this to decide how you will proceed by exploiting what others have done, and learning from their experience.
- You will know what your expected contributions are.
- You may even be able to solve the problem statement just from the literature study. No experiment needed.

3: Experiment Design

- This is a full description of *how* the experiments that you will do will be designed and run.
- It provides a mechanism to make experiments *repeatable*. In other words for an experiment to prove something it needs to always give the same results under the same conditions.
- Also demonstrates *how* you will get quantitative data that has meaning.

- Full description of all materials and methods.
- Full description of all equipment and processes.
- Full description of material sources and suppliers.
- Full description of any human or animal subjects used.
- Full description of the environment under which the experiments are run and data is collected.

- This all allows for independent verification of your results.
- You also need it to get a patent.

4: Data Collection

- This describes the nature of the raw data that is collected.
- It needs to actually be a measure of quantities that addresses your problem statement and hypothesis. In other words, you need to measure the right thing.
- It takes into account *accuracy*, *precision* and *resolution*.
- It addresses any unavoidable *bias* that the data may have.
- The *amount of data* that is collected is important.

5: Data Analysis

- In this step you summarize your raw data in a way that:
- Any competent researcher in your field can understand your data without having to look at every measured value.
- Allows your data to show trends, variance, probabilities, errors or any other quantities that allow the "data to speak" for you.
- Allows the *significance* of the data to be understood. In other words, does the data mean anything and if so then what?

6: Study Conclusions

- It is here that you connect your data with your hypothesis.
- In a deductive study, you use the data to confirm or reject your hypothesis.
- In a inductive study, you use the data to form a "tentative hypothesis" that can lead to a theory.
- You also can explicitly state what *impact* your study ultimately has. In other words, what is the bigger picture that the results of your study suggests? How does it compare with what you found in your literature study? For example:
- "The problem stated in the *problem statement* has been solved."
- "The technology is possible and will be disruptive in the market."
- "The basis for an entire new industry can be created."

7: References

References are necessary because they:

- Back up your claims.
- They also provide a basis for previous work that you rely on.
- Provide the reader with the resources to understand you.
- Allow the reader to verify your sources of information.
- Provide the background needed to replicate your results.

Quality in Research

Validity: How trustworthy the study is.

- That what is claimed to be measured actually is measured.
- That the study is credible. That it follows accepted rules and procedures.
- Valid outcomes. That the results are correctly understood.

Quality in Research

<u>Dependability</u>: Stability of the measurements and consistency of the results.

- Processes to audit every phase of the study.
- Full and available report on every phase of the research study.
- Peer review of the results.

Quality in Research

<u>Confirmability</u>: That the investigator has acted in good faith.

- No personal assessments
- Has not manipulated or affected the result of the study

<u>Transferability</u>: The research has created useful artifacts

- Descriptions, data, methods, processes and other output that become a database for others.

Next steps for you to take

- There are lots of methods, techniques and processes that can help you design and run good quantitative studies that give concrete results.
- Letting the data speak is a powerful tool for any scientist and engineer. Always let it speak for you if you can!
- In a future lecture we will go into the details of many of these steps and focus on what is important.
- In the lab sections we will try many of these methods, techniques and processes.