

The Complete Treatise on Research Methods

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Abstract

This treatise provides an integrative, cross-disciplinary synthesis of research methods spanning philosophy of science, study design, measurement theory, sampling, causal inference, quantitative and qualitative methodologies, mixed-methods design, computational and AI-augmented workflows, ethics, reproducibility, and reporting standards. We blend foundational principles with contemporary advances such as preregistration, registered reports, causal diagrams, target trial emulation, robust statistical workflows (frequentist and Bayesian), double/debiased machine learning, adaptive and sequential designs, synthetic data and differential privacy, and open science practices. Vector graphics illustrate key ideas including the research lifecycle, causal diagrams, and variance–bias trade-offs.

The treatise ends with “The End”

Keywords: research design; causal inference; Bayesian methods; reproducibility; open science; qualitative methods; mixed methods; machine learning; preregistration; differential privacy.

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1 Introduction

Research methods provide the systematic principles to transform questions into reliable knowledge. This includes epistemological grounding, design choices that align with causal and descriptive goals, rigorous measurement, appropriate sampling, transparent analysis plans, and ethical, reproducible dissemination. Foundational ideas from [Fisher (1925), Tukey (1977)] and [Neyman and Pearson (1933)] remain essential, while modern advances in causal inference [Pearl (2009), Imbens and Rubin (2015), Hernán and Robins (2020)], Bayesian workflow [Gelman et al. (2013)], and open science reshape contemporary practice.

2 Philosophy of Science and Epistemology

2.1 Scientific reasoning

- Deductive, inductive, and abductive reasoning guide theory and hypothesis formation. - Popperian falsifiability, Lakatosian research programs, and Kuhnian paradigm shifts frame scientific progress. - Construct validity and operationalization bridge theory and measurement.

2.2 Validity and reliability

- Internal validity, external validity, construct validity, and statistical conclusion validity [Shadish et al. (2002)]. - Reliability (test-retest, interrater, internal consistency); measurement invariance across groups. - Triangulation and convergent validity across methods and data sources.

3 Research Lifecycle

3.1 Concept-to-claims workflow



Figure 1: Research lifecycle distilled into five clear phases to reduce visual clutter.

4 Design: Experimental, Quasi-Experimental, and Observational

- Randomized controlled trials (parallel, crossover, cluster, adaptive). - Quasi-experiments: difference-in-differences, regression discontinuity, interrupted time series, instrumental variables [Shadish et al. (2002), Imbens and Rubin (2015)]. - Observational designs with target trial emulation [Hernán and Robins (2020)]. - Qualitative designs: ethnography, grounded theory, phenomenology; case studies and comparative methods; protocol transparency. - Mixed-methods: convergent, explanatory sequential, exploratory sequential; integration at design, analysis, and interpretation stages.

5 Measurement and Instruments

- Construct modeling, operational definitions, content validity. - Classical test theory vs. item response theory; reliability indices (Cronbachs α , McDonalds ω); measurement invariance. - Instrument development: cognitive interviewing, pilot testing, calibration, and validation.

6 Sampling and Power

- Probability sampling (simple random, stratified, cluster, multistage) vs. non-probability sampling (quota, convenience, snowball); implications for inference. - Power analysis for key estimands; minimum detectable effect; sequential and group-sequential designs. - Weighting and survey inference; design effects.

7 Causal Inference

7.1 Directed acyclic graphs (DAGs)

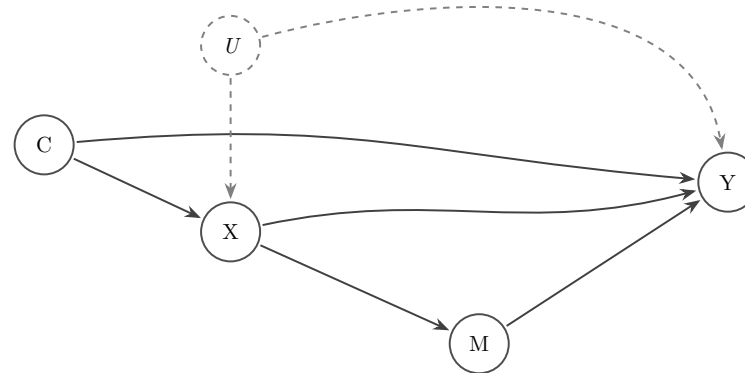


Figure 2: Causal DAG with increased spacing and curved edges to reduce overlap. C: confounder, X: exposure, M: mediator, Y: outcome, U: unobserved common cause.

7.2 Estimands and identification

- Estimands (ATE, ATT, CATE) and identification via randomization, ignorability, or instrumental variables. - Adjustment strategies: back-door, front-door, propensity scores, weighting, matching, outcome modeling, doubly robust estimators. - Target trial emulation for observational data [Hernán and Robins (2020)].

7.3 Modern causal ML

- Double/debiased machine learning for high-dimensional confounding [Chernozhukov et al. (2018)]. - Heterogeneous treatment effects and meta-learners (T-, S-, X-learners); honest forests; uplift modeling. - Sensitivity analysis and partial identification.

8 Quantitative Methods

8.1 Frequentist toolbox

- Linear and generalized linear models; mixed effects; robust/sandwich SEs. - Multiple testing: FWER, FDR control [Benjamini and Hochberg (1995)]. - Resampling: bootstrap, permutation tests; cross-validation. - Time series and panel methods; survival analysis.

8.2 Bayesian workflow

- Prior predictive checks, model fitting, posterior predictive checks, model comparison and averaging [Gelman et al. (2013)]. - Hierarchical modeling for partial pooling; regularization priors. - Decision analysis and utility.

8.3 Bias–variance trade-off

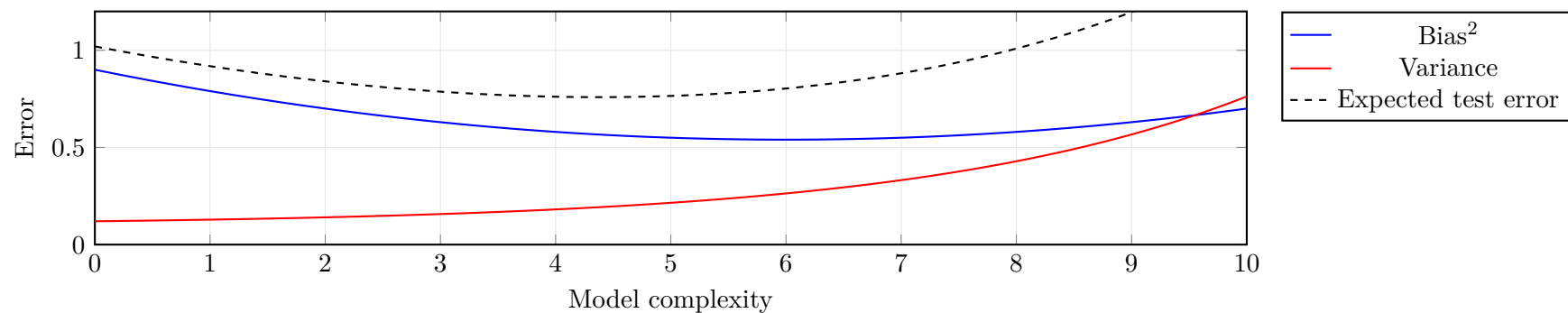


Figure 3: Illustrative bias–variance trade-off and test error curve.

9 Qualitative Methods

- Sampling for depth and diversity; saturation and information power.
- Data generation: interviews, focus groups, observation, documents; reflexivity and positionality.
- Analysis: thematic analysis, grounded theory coding, content analysis, process tracing; audit trails and transparency.
- Trustworthiness: credibility, transferability, dependability, confirmability; triangulation.

10 Mixed-Methods Integration

- Design typologies (convergent, explanatory sequential, exploratory sequential).
- Joint displays integrating quantitative and qualitative inferences.
- Inference quality and meta-inferences; resolving discrepant evidence.

11 Data Management, Reproducibility, and Open Science

- Preregistration and registered reports to reduce flexibility and bias.
- Computational reproducibility: version control, environments, literate programming, workflow automation.
- Data governance: de-identification, synthetic data, and differential privacy for sharing while protecting confidentiality.
- FAIR principles; code and data sharing; replication and robustness checks [Open Science Collaboration (2015)].

12 Ethics

- Risk–benefit analysis, informed consent, and equitable selection.
- Bias, fairness, and harms in data and algorithms; mitigation strategies.
- Data protection, privacy laws, and responsible AI.

13 Reporting Standards and Transparency

- Domain standards: CONSORT (randomized trials), PRISMA (systematic reviews), STROBE (observational studies), TRIPOD (prediction modeling).
- Clear estimands, assumptions, and limitations; sensitivity analyses.
- Graphic and tabular communication; uncertainty visualization.

14 Appendix: A Minimal Analysis Plan Template

Item	Guidance
Research question	Clearly state primary and secondary questions and theoretical motivation.
Estimands	Define target estimands (ATE/ATT/CATE; contrasts).
Design	Experimental/quasi-experimental/observational/qualitative; inclusion/exclusion; timeline.
Outcomes and measures	Primary/secondary outcomes; instruments; validation evidence.
Sampling and power	Frame, design, expected size, power/MDE, stopping rules.
Identification strategy	DAGs; adjustment sets; instruments; emulation protocol.
Statistical analysis	Models, priors (if Bayesian), tuning, robustness checks, multiplicity plan.
Missing data	Mechanism assumptions; imputation or modeling strategy.
Sensitivity	Unmeasured confounding, model misspecification, alternative estimators.
Reproducibility	Data/code availability; versioning; random seeds; computational environment.
Ethics	Consent, risk mitigation, privacy, DEI considerations.

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