

Trustworthy Online Controlled Experiments

A Practical Guide to A/B Testing

Getting numbers is easy; getting numbers you can trust is hard. This practical guide by experimentation leaders at Google, LinkedIn, and Microsoft will teach you how to accelerate innovation using trustworthy online controlled experiments, or A/B tests. Based on practical experiences at companies that each runs more than 20,000 controlled experiments a year, the authors share examples, pitfalls, and advice for students and industry professionals getting started with experiments, plus deeper dives into advanced topics for experienced practitioners who want to improve the way they and their organizations make data-driven decisions.

Learn how to:

- Use the scientific method to evaluate hypotheses using controlled experiments
- Define key metrics and ideally an Overall Evaluation Criterion
- Test for trustworthiness of the results and alert experimenters to violated assumptions
- Interpret and iterate quickly based on the results
- Implement guardrails to protect key business goals
- Build a scalable platform that lowers the marginal cost of experiments close to zero
- Avoid pitfalls such as carryover effects, Twyman's law, Simpson's paradox, and network interactions
- Understand how statistical issues play out in practice, including common violations of assumptions

RON KOHAVI is a vice president and technical fellow at Airbnb. This book was written while he was a technical fellow and corporate vice president at Microsoft. He was previously director of data mining and personalization at Amazon. He received his PhD in Computer Science from Stanford University. His papers have more than 40,000 citations and three of them are in the top 1,000 most-cited papers in Computer Science.

DIANE TANG is a Google Fellow, with expertise in large-scale data analysis and infrastructure, online controlled experiments, and ads systems. She has an AB from Harvard and an MS/PhD from Stanford, with patents and publications in mobile networking, information visualization, experiment methodology, data infrastructure, data mining, and large data.

YA XU heads Data Science and Experimentation at LinkedIn. She has published several papers on experimentation and is a frequent speaker at top-tier conferences and universities. She previously worked at Microsoft and received her PhD in Statistics from Stanford University.

“At the core of the Lean Methodology is the scientific method: Creating hypotheses, running experiments, gathering data, extracting insight and validation or modification of the hypothesis. A/B testing is the gold standard of creating verifiable and repeatable experiments, and this book is its definitive text.”

– Steve Blank, Adjunct professor at Stanford University, father of modern entrepreneurship, author of *The Startup Owner’s Manual* and *The Four Steps to the Epiphany*

“This book is a great resource for executives, leaders, researchers or engineers looking to use online controlled experiments to optimize product features, project efficiency or revenue. I know firsthand the impact that Kohavi’s work had on Bing and Microsoft, and I’m excited that these learnings can now reach a wider audience.”

– Harry Shum, EVP, Microsoft Artificial Intelligence and Research Group

“A great book that is both rigorous and accessible. Readers will learn how to bring trustworthy controlled experiments, which have revolutionized internet product development, to their organizations”

– Adam D’Angelo, Co-founder and CEO of Quora and former CTO of Facebook

“This book is a great overview of how several companies use online experimentation and A/B testing to improve their products. Kohavi, Tang and Xu have a wealth of experience and excellent advice to convey, so the book has lots of practical real world examples and lessons learned over many years of the application of these techniques at scale.”

– Jeff Dean, Google Senior Fellow and SVP Google Research

“Do you want your organization to make consistently better decisions? This is the new bible of how to get from data to decisions in the digital age. Reading this book is like sitting in meetings inside Amazon, Google, LinkedIn, Microsoft. The authors expose for the first time the way the world’s most successful companies make decisions. Beyond the admonitions and anecdotes of normal business books, this book shows what to do and how to do it well. It’s the how-to manual for decision-making in the digital world, with dedicated sections for business leaders, engineers, and data analysts.”

– Scott Cook, Intuit Co-founder & Chairman of the Executive Committee

“Online controlled experiments are powerful tools. Understanding how they work, what their strengths are, and how they can be optimized can illuminate both specialists and a wider audience. This book is the rare combination of technically authoritative, enjoyable to read, and dealing with highly important matters”

– John P.A. Ioannidis, Professor of Medicine, Health Research and Policy, Biomedical Data Science, and Statistics at Stanford University

“Which online option will be better? We frequently need to make such choices, and frequently err. To determine what will actually work better, we need rigorous controlled experiments, aka A/B testing. This excellent and lively book by experts from Microsoft, Google, and LinkedIn presents the theory and best practices of A/B testing. A must read for anyone who does anything online!”

– Gregory Piatetsky-Shapiro, Ph.D., president of KDnuggets, co-founder of SIGKDD, and LinkedIn Top Voice on Data Science & Analytics.

“Ron Kohavi, Diane Tang and Ya Xu are the world’s top experts on online experiments. I’ve been using their work for years and I’m delighted they have now teamed up to write the definitive guide. I recommend this book to all my students and everyone involved in online products and services.”

– Erik Brynjolfsson, Professor at MIT and Co-Author of
The Second Machine Age

“A modern software-supported business cannot compete successfully without online controlled experimentation. Written by three of the most experienced leaders in the field, this book presents the fundamental principles, illustrates them with compelling examples, and digs deeper to present a wealth of practical advice. It’s a “must read”!

– Foster Provost, Professor at NYU Stern School of Business & co-author of the best-selling *Data Science for Business*

“In the past two decades the technology industry has learned what scientists have known for centuries: that controlled experiments are among the best tools to understand complex phenomena and to solve very challenging problems. The ability to design controlled experiments, run them at scale, and interpret their results is the foundation of how modern high tech businesses operate. Between them the authors have designed and implemented several of the world’s most powerful experimentation platforms. This book is a great opportunity to learn from their experiences about how to use these tools and techniques.”

– Kevin Scott, EVP and CTO of Microsoft

“Online experiments have fueled the success of Amazon, Microsoft, LinkedIn and other leading digital companies. This practical book gives the reader rare access to decades of experimentation experience at these companies and should be on the bookshelf of every data scientist, software engineer and product manager.”

– Stefan Thomke, William Barclay Harding Professor, Harvard Business School,
Author of *Experimentation Works: The Surprising Power of Business Experiments*

“The secret sauce for a successful online business is experimentation. But it is a secret no longer. Here three masters of the art describe the ABCs of A/B testing so that you too can continuously improve your online services.”

– Hal Varian, Chief Economist, Google, and author of
Intermediate Microeconomics: A Modern Approach

“Experiments are the best tool for online products and services. This book is full of practical knowledge derived from years of successful testing at Microsoft Google and LinkedIn. Insights and best practices are explained with real examples and pitfalls, their markers and solutions identified. I strongly recommend this book!”

– Preston McAfee, former Chief Economist and VP of Microsoft

“Experimentation is the future of digital strategy and ‘Trustworthy Experiments’ will be its Bible. Kohavi, Tang and Xu are three of the most noteworthy experts on experimentation working today and their book delivers a truly practical roadmap for digital experimentation that is useful right out of the box. The revealing case studies they conducted over many decades at Microsoft, Amazon, Google and LinkedIn are organized into easy to understand practical lessons with tremendous depth and clarity. It should be required reading for any manager of a digital business.”

– Sinan Aral, David Austin Professor of Management,
MIT and author of *The Hype Machine*

“Indispensable for any serious experimentation practitioner, this book is highly practical and goes in-depth like I’ve never seen before. It’s so useful it feels like you get a superpower. From statistical nuances to evaluating outcomes to measuring long term impact, this book has got you covered. Must-read.”

– Peep Laja, top conversion rate expert, Founder and Principal of CXL

“Online experimentation was critical to changing the culture at Microsoft. When Satya talks about “Growth Mindset,” experimentation is the best way to try new ideas and learn from them. Learning to quickly iterate controlled experiments drove Bing to profitability, and rapidly spread across Microsoft through Office, Windows, and Azure.”

– Eric Boyd, Corporate VP, AI Platform, Microsoft

“As an entrepreneur, scientist, and executive I’ve learned (the hard way) that an ounce of data is worth a pound of my intuition. But how to get good data? This book compiles decades of experience at Amazon, Google, LinkedIn, and Microsoft into an accessible, well-organized guide. It is the bible of online experiments.”

– Oren Etzioni, CEO of Allen Institute of AI and
Professor of Computer Science at University of Washington

“Internet companies have taken experimentation to an unprecedented scale, pace, and sophistication. These authors have played key roles in these developments and readers are fortunate to be able to learn from their combined experiences.”

– Dean Eckles, KDD Career Development Professor in Communications and
Technology at MIT and former scientist at Facebook

“A wonderfully rich resource for a critical but under-appreciated area. Real case studies in every chapter show the inner workings and learnings of successful businesses. The focus on developing and optimizing an “Overall Evaluation Criterion” (OEC) is a particularly important lesson.”

– Jeremy Howard, Singularity University, founder of fast.ai,
and former president and chief scientist of Kaggle

“There are many guides to A/B Testing, but few with the pedigree of Trustworthy Online Controlled Experiments. I’ve been following Ronny Kohavi for eighteen years and find his advice to be steeped in practice, honed by experience, and tempered by doing laboratory work in real world environments. When you add Diane Tang, and Ya Xu to the mix, the breadth of comprehension is unparalleled. I challenge you to compare this tome to any other - in a controlled manner, of course.”

– Jim Sterne, Founder of Marketing Analytics Summit and
Director Emeritus of the Digital Analytics Association

“An extremely useful how-to book for running online experiments that combines analytical sophistication, clear exposition and the hard-won lessons of practical experience.”

– Jim Manzi, Founder of Foundry.ai, Founder and former CEO and
Chairman of Applied Predictive Technologies, and author of *Uncontrolled:
The Surprising Payoff of Trial-and-Error for Business, Politics, and Society*

“Experimental design advances each time it is applied to a new domain: agriculture, chemistry, medicine and now online electronic commerce. This book by three top experts is rich in practical advice and examples covering both how and why to experiment online and not get fooled. Experiments can be expensive; not knowing what works can cost even more.”

– Art Owen Professor of Statistics, Stanford University

“This is a must read book for business executives and operating managers. Just as operations, finance, accounting and strategy form the basic building blocks for business, today in the age of AI, understanding and executing online controlled experiments will be a required knowledge set. Kohavi, Tang and Xu have laid out the essentials of this new and important knowledge domain that is practically accessible.”

– Karim R. Lakhani, Professor and Director of Laboratory for Innovation Science at Harvard, Board Member, Mozilla Corp.

“Serious ‘data-driven’ organizations understand that analytics aren’t enough; they must commit to experiment. Remarkably accessible and accessibly remarkable, this book is a manual and manifesto for high-impact experimental design. I found its pragmatism inspirational. Most importantly, it clarifies how culture rivals technical competence as a critical success factor.”

– Michael Schrage, research fellow at MIT’s Initiative on the Digital Economy and author of *The Innovator’s Hypothesis: How Cheap Experiments Are Worth More than Good Ideas*

“This important book on experimentation distills the wisdom of three distinguished leaders from some of the world’s biggest technology companies. If you are a software engineer, data scientist, or product manager trying to implement a data-driven culture within your organization, this is an excellent and practical book for you.”

– Daniel Tunkelang, Chief Scientist at Endeca and former Director of Data Science and Engineering at LinkedIn

“With every industry becoming digitized and data-driven, conducting and benefiting from controlled online experiments becomes a required skill. Kohavi, Tang and Yu provide a complete and well-researched guide that will become necessary reading for data practitioners and executives alike.”

– Evangelos Simoudis, Co-founder and Managing Director Synapse Partners; author of *The Big Data Opportunity in Our Driverless Future*

“The authors offer over 10 years of hard-fought lessons in experimentation, in the most strategic book for the discipline yet”

– Colin McFarland, Director Experimentation Platform at Netflix

“The practical guide to A/B testing distills the experiences from three of the top minds in experimentation practice into easy and digestible chunks of valuable and practical concepts. Each chapter walks you through some of the most important considerations when running experiments - from choosing the right metric to the benefits of institutional memory. If you are looking for an experimentation coach that balances science and practicality, then this book is for you.”

– Dylan Lewis, Experimentation Leader, Intuit

“The only thing worse than no experiment is a misleading one, because it gives you false confidence! This book details the technical aspects of testing based on insights from some of the world’s largest testing programs. If you’re involved in online experimentation in any capacity, read it now to avoid mistakes and gain confidence in your results.”

- Chris Goward, Author of *You Should Test That!*,
Founder and CEO of Widerfunnel

“This is a phenomenal book. The authors draw on a wealth of experience and have produced a readable reference that is somehow both comprehensive and detailed at the same time. Highly recommended reading for anyone who wants to run serious digital experiments.”

- Pete Koomen, Co-founder, Optimizely

“The authors are pioneers of online experimentation. The platforms they’ve built and the experiments they’ve enabled have transformed some of the largest internet brands. Their research and talks have inspired teams across the industry to adopt experimentation. This book is the authoritative yet practical text that the industry has been waiting for.”

- Adil Aijaz, Co-founder and CEO, Split Software

Trustworthy Online Controlled
Experiments
A Practical Guide to A/B Testing

RON KOHAVI
Microsoft

DIANE TANG
Google

YA XU
LinkedIn



CAMBRIDGE
UNIVERSITY PRESS

Cambridge University Press & Assessment
978-1-108-72426-5 — Trustworthy Online Controlled Experiments
Ron Kohavi, Diane Tang, Ya Xu
Frontmatter
[More Information](#)

CAMBRIDGE UNIVERSITY PRESS

University Printing House, Cambridge CB2 8BS, United Kingdom
One Liberty Plaza, 20th Floor, New York, NY 10006, USA
477 Williamstown Road, Port Melbourne, VIC 3207, Australia
314–321, 3rd Floor, Plot 3, Splendor Forum, Jasola District Centre,
New Delhi – 110025, India
103 Penang Road, #05-06/07, Visioncrest Commercial, Singapore 238467

Cambridge University Press is part of the University of Cambridge.

It furthers the University's mission by disseminating knowledge in the pursuit of education, learning, and research at the highest international levels of excellence.

www.cambridge.org

Information on this title: www.cambridge.org/9781108724265

DOI: 10.1017/9781108653985

© Ron Kohavi, Diane Tang, and Ya Xu 2020

This publication is in copyright. Subject to statutory exception and to the provisions of relevant collective licensing agreements, no reproduction of any part may take place without the written permission of Cambridge University Press.

First published 2020

5th printing 2022

Printed in the United Kingdom by TJ Books Limited, Padstow Cornwall

A catalogue record for this publication is available from the British Library.

Library of Congress Cataloging-in-Publication Data

Names: Kohavi, Ron, author. | Tang, Diane, 1974– author. | Xu, Ya, 1982– author.

Title: Trustworthy online controlled experiments : a practical guide to A/B testing / Ron Kohavi, Diane Tang, Ya Xu.

Description: Cambridge, United Kingdom ; New York, NY : Cambridge University Press, 2020. | Includes bibliographical references and index.

Identifiers: LCCN 2019042021 (print) | LCCN 2019042022 (ebook) | ISBN 9781108724265 (paperback) | ISBN 9781108653985 (epub)

Subjects: LCSH: Social media. | User-generated content—Social aspects.

Classification: LCC HM741 .K68 2020 (print) | LCC HM741 (ebook) | DDC 302.23/1—dc23
LC record available at <https://lcn.loc.gov/2019042021>

LC ebook record available at <https://lcn.loc.gov/2019042022>

ISBN 978-1-108-72426-5 Paperback

Cambridge University Press has no responsibility for the persistence or accuracy of URLs for external or third-party internet websites referred to in this publication and does not guarantee that any content on such websites is, or will remain, accurate or appropriate.

Contents

	<i>Preface – How to Read This Book</i>	page xv
	<i>Acknowledgments</i>	xvii
	PART I INTRODUCTORY TOPICS FOR EVERYONE	1
1	Introduction and Motivation	3
	Online Controlled Experiments Terminology	5
	Why Experiment? Correlations, Causality, and Trustworthiness	8
	Necessary Ingredients for Running Useful Controlled Experiments	10
	Tenets	11
	Improvements over Time	14
	Examples of Interesting Online Controlled Experiments	16
	Strategy, Tactics, and Their Relationship to Experiments	20
	Additional Reading	24
2	Running and Analyzing Experiments: An End-to-End Example	26
	Setting up the Example	26
	Hypothesis Testing: Establishing Statistical Significance	29
	Designing the Experiment	32
	Running the Experiment and Getting Data	34
	Interpreting the Results	34
	From Results to Decisions	36
3	Twyman’s Law and Experimentation Trustworthiness	39
	Misinterpretation of the Statistical Results	40
	Confidence Intervals	43
	Threats to Internal Validity	43
	Threats to External Validity	48

x	Contents	
	Segment Differences	52
	Simpson's Paradox	55
	Encourage Healthy Skepticism	57
4	Experimentation Platform and Culture	58
	Experimentation Maturity Models	58
	Infrastructure and Tools	66
	PART II SELECTED TOPICS FOR EVERYONE	79
5	Speed Matters: An End-to-End Case Study	81
	Key Assumption: Local Linear Approximation	83
	How to Measure Website Performance	84
	The Slowdown Experiment Design	86
	Impact of Different Page Elements Differs	87
	Extreme Results	89
6	Organizational Metrics	90
	Metrics Taxonomy	90
	Formulating Metrics: Principles and Techniques	94
	Evaluating Metrics	96
	Evolving Metrics	97
	Additional Resources	98
	SIDEBAR: Guardrail Metrics	98
	SIDEBAR: Gameability	100
7	Metrics for Experimentation and the Overall Evaluation Criterion	102
	From Business Metrics to Metrics Appropriate for Experimentation	102
	Combining Key Metrics into an OEC	104
	Example: OEC for E-mail at Amazon	106
	Example: OEC for Bing's Search Engine	108
	Goodhart's Law, Campbell's Law, and the Lucas Critique	109
8	Institutional Memory and Meta-Analysis	111
	What Is Institutional Memory?	111
	Why Is Institutional Memory Useful?	112
9	Ethics in Controlled Experiments	116
	Background	116
	Data Collection	121
	Culture and Processes	122
	SIDEBAR: User Identifiers	123

Contents

xi

PART III COMPLEMENTARY AND ALTERNATIVE TECHNIQUES TO CONTROLLED EXPERIMENTS	125
10 Complementary Techniques	127
The Space of Complementary Techniques	127
Logs-based Analysis	128
Human Evaluation	130
User Experience Research (UER)	131
Focus Groups	132
Surveys	132
External Data	133
Putting It All Together	135
11 Observational Causal Studies	137
When Controlled Experiments Are Not Possible	137
Designs for Observational Causal Studies	139
Pitfalls	144
SIDEBAR: Refuted Observational Causal Studies	147
PART IV ADVANCED TOPICS FOR BUILDING AN EXPERIMENTATION PLATFORM	151
12 Client-Side Experiments	153
Differences between Server and Client Side	153
Implications for Experiments	156
Conclusions	161
13 Instrumentation	162
Client-Side vs. Server-Side Instrumentation	162
Processing Logs from Multiple Sources	164
Culture of Instrumentation	165
14 Choosing a Randomization Unit	166
Randomization Unit and Analysis Unit	168
User-level Randomization	169
15 Ramping Experiment Exposure: Trading Off Speed, Quality, and Risk	171
What Is Ramping?	171
SQR Ramping Framework	172
Four Ramp Phases	173
Post Final Ramp	176

16	Scaling Experiment Analyses	177
	Data Processing	177
	Data Computation	178
	Results Summary and Visualization	180
	PART V ADVANCED TOPICS FOR ANALYZING EXPERIMENTS	183
17	The Statistics behind Online Controlled Experiments	185
	Two-Sample t-Test	185
	p-Value and Confidence Interval	186
	Normality Assumption	187
	Type I/II Errors and Power	189
	Bias	191
	Multiple Testing	191
	Fisher's Meta-analysis	192
18	Variance Estimation and Improved Sensitivity: Pitfalls and Solutions	193
	Common Pitfalls	193
	Improving Sensitivity	196
	Variance of Other Statistics	198
19	The A/A Test	200
	Why A/A Tests?	200
	How to Run A/A Tests	205
	When the A/A Test Fails	207
20	Triggering for Improved Sensitivity	209
	Examples of Triggering	209
	A Numerical Example (Kohavi, Longbotham et al. 2009)	212
	Optimal and Conservative Triggering	213
	Overall Treatment Effect	214
	Trustworthy Triggering	215
	Common Pitfalls	216
	Open Questions	217
21	Sample Ratio Mismatch and Other Trust-Related Guardrail Metrics	219
	Sample Ratio Mismatch	219
	Debugging SRMs	222

Contents		xiii
22	Leakage and Interference between Variants	226
	Examples	227
	Some Practical Solutions	230
	Detecting and Monitoring Interference	234
23	Measuring Long-Term Treatment Effects	235
	What Are Long-Term Effects?	235
	Reasons the Treatment Effect May Differ between Short-Term and Long-Term	236
	Why Measure Long-Term Effects?	238
	Long-Running Experiments	239
	Alternative Methods for Long-Running Experiments	241
	<i>References</i>	246
	<i>Index</i>	266

Preface

How to Read This Book

If we have data, let's look at data.

If all we have are opinions, let's go with mine

— Jim Barksdale, Former CEO of Netscape

Our goal in writing this book is to share practical lessons from decades of experience running online controlled experiments at scale at Amazon and Microsoft (Ron), Google (Diane), and Microsoft and LinkedIn (Ya). While we are writing this book in our capacity as individuals and not as representatives of Google, LinkedIn, or Microsoft, we have distilled key lessons and pitfalls encountered over the years and provide guidance for both software platforms and the corporate cultural aspects of using online controlled experiments to establish a data-driven culture that informs rather than relies on the HiPPO (Highest Paid Person's Opinion) (R. Kohavi, HiPPO FAQ 2019). We believe many of these lessons apply in the online setting, to large or small companies, or even teams and organizations within a company. A concern we share is the need to evaluate the trustworthiness of experiment results. We believe in the skepticism implied by Twyman's Law: *Any figure that looks interesting or different is usually wrong*; we encourage readers to double-check results and run validity tests, especially for breakthrough positive results. Getting numbers is easy; getting numbers you can trust is hard!

Part I is designed to be read by everyone, regardless of background, and consists of four chapters.

- Chapter 1 is an overview of the benefits of running online controlled experiments and introduces experiment terminology.
- Chapter 2 uses an example to run through the process of running an experiment end-to-end.
- Chapter 3 describes common pitfalls and how to build experimentation trustworthiness, and

- Chapter 4 overviews what it takes to build an experiment platform and scale online experimentation.

Parts II through V can be consumed by everyone as needed but are written with a focus on a specific audience. Part II contains five chapters on fundamentals, such as Organizational Metrics. The topics in Part II are recommended for everyone, especially leaders and executives. Part III contains two chapters that introduce techniques to complement online controlled experiments that leaders, data scientists, engineers, analysts, product managers, and others would find useful for guiding resources and time investment. Part IV focuses on building an experimentation platform and is aimed toward engineers. Finally, Part V digs into advanced analysis topics and is geared toward data scientists.

Our website, <https://experimentguide.com>, is a companion to this book. It contains additional material, errata, and provides an area for open discussion. The authors intend to donate all proceeds from this book to charity.

Acknowledgments

We would like to thank our colleagues who have worked with us throughout the years. While too numerous to name individually, this book is based on our combined work, as well as others throughout the industry and beyond researching and conducting online controlled experiments. We learned a great deal from you all, thank you.

On writing the book, we'd like to call out Lauren Cowles, our editor, for partnering with us throughout this process. Cherie Woodward provided great line editing and style guidance to help mesh our three voices. Stephanie Grey worked with us on all diagrams and figures, improving them in the process. Kim Vernon provided final copy-editing and bibliography checks.

Most importantly, we owe a deep debt of gratitude to our families, as we missed time with them to work on this book. Thank you to Ronny's family: Yael, Oren, Ittai, and Noga, to Diane's family: Ben, Emma, and Leah, and to Ya's family: Thomas, Leray, and Tavis. We could not have written this book without your support and enthusiasm!

Google: Hal Varian, Dan Russell, Carrie Grimes, Niall Cardin, Deirdre O'Brien, Henning Hohnhold, Mukund Sundararajan, Amir Najmi, Patrick Riley, Eric Tassone, Jen Gennai, Shannon Vallor, Eric Miraglia, David Price, Crystal Dahlen, Tammy Jih Murray, Lanah Donnelly and all who work on experiments at Google.

LinkedIn: Stephen Lynch, Yav Bojinov, Jiada Liu, Weitao Duan, Nanyu Chen, Guillaume Saint-Jacques, Elaine Call, Min Liu, Arun Swami, Kiran Prasad, Igor Perisic, and the entire Experimentation team.

Microsoft: Omar Alonso, Benjamin Arai, Jordan Atlas, Richa Bhayani, Eric Boyd, Johnny Chan, Alex Deng, Andy Drake, Aleksander Fabijan, Brian Frasca, Scott Gude, Somit Gupta, Adam Gustafson, Tommy Guy, Randy Henne, Edward Jezierski, Jing Jin, Dongwoo Kim, Waldo Kuipers, Jonathan Litz, Sophia Liu, Jiannan Lu, Qi Lu, Daniel Miller, Carl Mitchell, Nils

Pohlmann, Wen Qin, Thomas Schreiter, Harry Shum, Dan Sommerfield, Garnet Vaz, Toby Walker, Michele Zunker, and the Analysis & Experimentation team.

Special thanks to Maria Stone and Marcus Persson for feedback throughout the book, and Michelle N. Meyer for expert feedback on the ethics chapter

Others who have given feedback include: Adil Aijaz, Jonas Alves, Alon Amit, Kevin Anderson, Joel Barajas, Houman Bedayat, Beau Bender, Bahador Biglari, Stuart Buck, Jake Chong, Jed Chou, Pavel Dmitriev, Yurong Fan, Georgi Georgiev, Ilias Gerostathopoulos, Matt Gershoff, William Grosso, Aditya Gupta, Rajesh Gupta, Shilpa Gupta, Kris Jack, Jacob Jarnvall, Dave Karow, Slawek Kierner, Pete Koomen, Dylan Lewis, Bryan Liu, David Mannheim, Colin McFarland, Tanapol Nearunchron, Dheeraj Ravindranath, Aaditya Ramdas, Andre Richter, Jianhong Shen, Gang Su, Anthony Tang, Lukas Vermeer, Rowel Willems, Yu Yang, and Yufeng Wang.

Thank you to the many who helped who are not named explicitly.