An Introduction to Proof via Inquiry-Based Learning

Dana C. Ernst, PhD Northern Arizona University

Version Fall 2021

© 2021 Dana C. Ernst. Some Rights Reserved.

This book is intended to be a task sequence for an introduction to proof course that utilizes an inquiry-based learning (IBL) approach. You can find the most up-to-date version of this textbook on GitHub:

http://dcernst.github.io/IBL-IntroToProof/

I would be thrilled if you used this textbook and improved it. If you make any modifications, you can either make a pull request on GitHub or submit the improvements via email. You are also welcome to fork the source and modify the text for your purposes as long as you maintain the license below.

This work is licensed under the Creative Commons Attribution-Share Alike 4.0 United States License. You may copy, distribute, display, and perform this copyrighted work, but only if you give credit to Dana C. Ernst, and all derivative works based upon it must be published under the Creative Commons Attribution-Share Alike 4.0 International License. Please attribute this work to Dana C. Ernst, Mathematics Faculty at Northern Arizona University, dana.ernst@nau.edu, as well as the individuals listed below. To view a copy of this license, visit

```
https://creativecommons.org/licenses/by-sa/4.0/
```

or send a letter to Creative Commons, 171 Second Street, Suite 300, San Francisco, California, 94105, USA.



Contents

	Pref	ace	4	
	Ack	nowledgements	6	
1	Introduction			
	1.1	What is This Book All About?	8	
	1.2	An Inquiry-Based Approach	9	
	1.3	Structure of the Textbook	11	
	1.4	Rights of the Learner	12	
	1.5	Some Minimal Guidance	12	
2	Mathematics and Logic 15			
	2.1	A Taste of Number Theory	15	
	2.2	Introduction to Logic	19	
	2.3	Techniques for Proving Conditional Propositions	25	
	2.4	Introduction to Quantification	28	
	2.5	More About Quantification	32	
3	Set Theory 39			
	3.1	Sets	39	
	3.2	Russell's Paradox	43	
	3.3	Power Sets	45	
	3.4	Indexing Sets	46	
	3.5	Cartesian Products of Sets	49	
4	Induction 53			
	4.1	Introduction to Induction	53	
	4.2	More on Induction	56	
	4.3	Complete Induction and the Well-Ordering Principle	58	
5	The Real Numbers			
	5.1	Axioms of the Real Numbers	61	
	5.2	Standard Topology of the Real Line	70	

6	Three Famous Theorems6.1The Fundamental Theorem of Arithmetic6.2The Irrationality of $\sqrt{2}$ 6.3The Infinitude of Primes	76 76 80 81
7	Relations and Partitions7.1Relations7.2Equivalence Relations7.3Partitions7.4Modular Arithmetic	83 83 90 92 95
8		113 117
9	9.1 Introduction to Cardinality9.2 Finite Sets9.3 Infinite Sets9.4 Countable Sets	129 130
A	Elements of Style for Proofs	139
B	B Fancy Mathematical Terms	
C	C Paradoxes	
D	D Definitions in Mathematics	

Acknowledgements

The first draft of this book was written in 2009. At that time, several of the sections were adaptations of course materials written by Matthew Jones (CSU Dominguez Hills) and Stan Yoshinobu (University of Toronto). The current version of the book is the result of many iterations that involved the addition of new material, retooling of existing sections, and feedback from instructors that have used the book. The current version of the book is a far cry from what it looked like in 2009.

This book has been an open-source project since day one. Instructors and students can download the PDF for free and modify the source as they see fit. Several of instructors and students have provided extremely useful feedback, which has improved the book at each iteration. Moreover, due to the open-source nature of the book, I have been able to incorporate content written by others. Below is a partial list of people (alphabetical by last name) that have contributed content, advice, or feedback.

- Chris Drupieski, T. Kyle Petersen, and Bridget Tenner (DePaul University). Modifications that these three made to the book inspired me to streamline some of the exposition, especially in the early chapters.
- Paul Ellis (Manhattanville College). Paul has provided lots of useful feedback and several suggestions for improvements. Paul suggested problems for Chapter 4 and provided an initial draft of Section 8.4: Images and Inverse Images.
- Jason Grout (Bloomberg, L.P.). I am extremely grateful to Jason for feedback on early versions of this manuscript, as well as for helping me with a variety of technical aspects of writing an open-source textbook.
- Anders Hendrickson (St. Norbert College). Anders is the original author of the content in Appendix A: Elements of Style for Proofs. The current version in Appendix A is a result of modifications made by myself with some suggestions from David Richeson.
- Rebecca Jayne (Hampden–Sydney College). The current version of Section 4.3: Complete Induction is a derivative of content contributed by Rebecca.
- Matthew Jones (CSU Dominguez Hills) and Stan Yoshinobu (University of Toronto). A few of the sections were originally adaptations of notes written by Matt and Stan. Early versions of this textbook relied heavily on their work. Moreover, Matt and Stan were two of the key players that contributed to shaping my approach to teaching.

- Crystal Kalinec-Craig (University of Texas at San Antonio). Section 1.4: Rights of the Learner is an adaptation of a similar list written by Crystal.
- David Richeson (Dickinson College). David is responsible for much of the content in Appendix B: Fancy Mathematical Terms, Appendix C: Paradoxes, and Appendix D: Definitions in Mathematics. In addition, the current version of Chapter 6: Three Famous Theorems is heavily based on content contributed by David.
- Carol Schumacher (Kenyon College). When I was transitioning to an IBL approach to teaching, Carol was one of my mentors and played a significant role in my development as a teacher. Moreover, this work is undoubtably influenced my Carol's excellent book *Chapter Zero: Fundamental Notions of Advanced Mathematics*, which I used when teaching my very first IBL course.
- Josh Wiscons (CSU Sacramento). The current version of Section 7.4: Modular Arithmetic is a derivative of content contributed by Josh.