Contents

Volume 1

List of Entries vii
Reader’s Guide xi
About the Editor xv
List of Contributors xvii
Introduction xxi

Entries
A 1 G 299
B 57 H 343
C 113 I 363
D 209 J 423
E 229 K 429
F 279 L 439

Volume 2

List of Entries vii
Reader’s Guide xi

Entries
M 501 T 893
N 603 U 931
p 629 V 935
R 767 W 945
S 799

Appendix: Resource Guide 957
Index 961
<table>
<thead>
<tr>
<th>List of Entries</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abduction</td>
</tr>
<tr>
<td>Abstract Knowledge</td>
</tr>
<tr>
<td>Abstraction</td>
</tr>
<tr>
<td>Accuracy</td>
</tr>
<tr>
<td>Actor-Network Theory</td>
</tr>
<tr>
<td>ad Hoc Hypothesis</td>
</tr>
<tr>
<td>Analysis</td>
</tr>
<tr>
<td>Applicability of Mathematics in Science</td>
</tr>
<tr>
<td>Artificial Intelligence</td>
</tr>
<tr>
<td>Assumption</td>
</tr>
<tr>
<td>Astronomy. See Cosmology</td>
</tr>
<tr>
<td>Authority</td>
</tr>
<tr>
<td>Axiom Schema</td>
</tr>
<tr>
<td>Axiomatic Theory</td>
</tr>
<tr>
<td>Concept</td>
</tr>
<tr>
<td>Conceptual Analysis</td>
</tr>
<tr>
<td>Conceptual Blending</td>
</tr>
<tr>
<td>Consilience</td>
</tr>
<tr>
<td>Cosmology</td>
</tr>
<tr>
<td>Cybernetics, 20th Century</td>
</tr>
<tr>
<td>Data and Phenomena</td>
</tr>
<tr>
<td>Data Mining. See Big Data</td>
</tr>
<tr>
<td>Data Models</td>
</tr>
<tr>
<td>Deduction</td>
</tr>
<tr>
<td>Developmental Systems Theory</td>
</tr>
<tr>
<td>Ecology. See Environmental Studies; Natural Resources</td>
</tr>
<tr>
<td>Empiricism. See Epistemology; Evidence; Experiment, Theory of Engineering, Contemporary</td>
</tr>
<tr>
<td>Engineering, History of Environmental Studies</td>
</tr>
<tr>
<td>Epistemology</td>
</tr>
<tr>
<td>Evidence</td>
</tr>
<tr>
<td>Evolutionary Psychology</td>
</tr>
<tr>
<td>Experiment, Theory of Explanation</td>
</tr>
<tr>
<td>Fact Versus Theory</td>
</tr>
<tr>
<td>Falsifiability</td>
</tr>
<tr>
<td>Formal Sciences</td>
</tr>
<tr>
<td>Framework</td>
</tr>
<tr>
<td>Game Theory</td>
</tr>
<tr>
<td>Generalization</td>
</tr>
<tr>
<td>Genetic Drift</td>
</tr>
<tr>
<td>Geology</td>
</tr>
<tr>
<td>Geometry, Classical</td>
</tr>
<tr>
<td>Geometry, Non-Euclidean</td>
</tr>
<tr>
<td>Geophysics. See Geology</td>
</tr>
<tr>
<td>Germ Theory</td>
</tr>
<tr>
<td>Gödel’s Incompleteness Theorems</td>
</tr>
</tbody>
</table>
Health Care Science  
Hypothesis Testing  
Hypothetico-Deductivism

Induction  
Infectious Disease Studies  
Inference  
Inference to the Best Explanation  
Inferentialism  
Informatics  
Information Theory  
Information Theory, Historical Background  
Instrumentalism  
Interpretation  
Intuition  
Intuitionism in Logic and Mathematics

Justification

Kinetic (Molecular) Theory  
Knowledge

Laws, Scientific  
Laws of Nature  
Life Sciences, Contemporary  
Linguistic Frameworks  
Linguistics, Contemporary  
Linguistics, Historical  
Logic, Formal and Informal  
Logic, Inductive  
Logic and Language  
Logical Theory

Mathematics, Antiquity  
Mathematics, Enlightenment  
Mathematics, Middle Ages  
Mathematics, 19th Century  
Mathematics, Renaissance  
Mathematics, 20th Century  
Measurement  
Medicine, Antiquity  
Medicine, Contemporary  
Medicine, Enlightenment  
Medicine, Middle Ages  
Medicine, 19th Century  
Medicine, Renaissance  
Medicine, 20th Century. See Medicine, Contemporary; Medicine, 19th Century

Mental Models  
Metaphysics

Metatheory  
Meteorology. See Climate Science  
Modeling  
Nanotechnology  
Natural Resources  
Natural Selection  
Neuroscience  
Number Theory. See Mathematics, 19th Century; Mathematics, 20th Century

Paraconsistency  
Paradigm  
Paradoxes  
Perturbation Theory  
Phenomenalism  
Philosophy of Mind  
Philosophy of Science  
Physical Theory  
Physics, Antiquity  
Physics, Contemporary  
Physics, Enlightenment  
Physics, Gravitation Theory  
Physics, Middle Ages  
Physics, 19th Century  
Physics, Quantum Theory  
Physics, Renaissance  
Physics, Solid-State  
Physics, Thermodynamics  
Physics, 20th Century  
Plate Tectonics  
Pragmatism  
Prediction  
Pseudoscience  
Punctuated Equilibrium

Rational Mechanics  
Rationality  
Realism in Mathematics  
Realism in Science. See Scientific Realism  
Reasoning  
Received View of Theories. See Theory, Syntactic Conception  
Refutation  
Relative Consistency

Scientific Realism  
Scientific Revolutions  
Semantics (Introduction to Theory)
<table>
<thead>
<tr>
<th>List of Entries</th>
</tr>
</thead>
<tbody>
<tr>
<td>Semantics (Scientific and Empirical)</td>
</tr>
<tr>
<td>Set Theory</td>
</tr>
<tr>
<td>Social Construction of Scientific Knowledge</td>
</tr>
<tr>
<td>Software Engineering</td>
</tr>
<tr>
<td>Soundness</td>
</tr>
<tr>
<td>Speculation</td>
</tr>
<tr>
<td>Statistical Inference, Bayesian</td>
</tr>
<tr>
<td>Statistical Inference, Frequentist</td>
</tr>
<tr>
<td>Statistics</td>
</tr>
<tr>
<td>Statistics, Completeness in</td>
</tr>
<tr>
<td>Structuralism (Introduction to Theory)</td>
</tr>
<tr>
<td>Syntax (Introduction to Theory)</td>
</tr>
<tr>
<td>Syntax (Scientific and Empirical)</td>
</tr>
<tr>
<td>Systems Science</td>
</tr>
<tr>
<td>Taxonomy</td>
</tr>
<tr>
<td>Theory Change</td>
</tr>
<tr>
<td>Theory Construction</td>
</tr>
<tr>
<td>Theory Structure</td>
</tr>
<tr>
<td>Theories, Semantic Conception of</td>
</tr>
<tr>
<td>Theories, Syntactic Conception of</td>
</tr>
<tr>
<td>Thought Experiments, Scientific and Philosophical</td>
</tr>
<tr>
<td>Truth</td>
</tr>
<tr>
<td>Understanding</td>
</tr>
<tr>
<td>Values in Science</td>
</tr>
<tr>
<td>Vitalism</td>
</tr>
<tr>
<td>Warrant</td>
</tr>
<tr>
<td>Worldview</td>
</tr>
</tbody>
</table>
Reader’s Guide

General Theory of Science
Abduction
Abstract Knowledge
Abstraction
Accuracy
Ad Hoc Hypothesis
Analysis
Authority
Belief Revision
Church–Turing Thesis
Communication Theory, Technical Overview
Completeness
Concept
Conceptual Analysis
Conceptual Blending
Consilience
Epistemology
Evidence
Experiment, Theory of
Explanation
Fact Versus Theory
Falsifiability
Formal Sciences
Generalization
Hypothesis Testing
Hypothetico-Deductivism
Induction
Inference
Inference to the Best Explanation
Inferentialism
Instrumentalism
Interpretation
Intuition
Justification
Knowledge
Mental Models
Metaphysics
Metatheory
Modeling
Paraconsistency
Paradigm
Paradoxes
Phenomenalism
Philosophy of Mind
Philosophy of Science
Physical Theory
Pragmatism
Prediction
Pseudoscience
Rationality
Realism in Mathematics
Reasoning
Scientific Realism
Scientific Revolutions
Social Construction of Scientific Knowledge
Speculation
Statistics
Taxonomy
Theory Change
Thought Experiments, Scientific and Philosophical
Truth
Understanding
Values in Science

Nature and Structure of Theories
Axiom Schema
Axiomatic Theory
Data Models
Framework
Geometry, Classical
Geometry, Non-Euclidean
Gödel’s Incompleteness Theorems
Instrumentalism
Intuitionism in Logic and Mathematics
Laws, Scientific
Laws of Nature
Linguistic Frameworks
Modeling
Paradigm
Philosophy of Science
Rational Mechanics
Received View of Theories
Relative Consistency
Set Theory
Theories, Semantic Conception of
Theories, Syntactic Conception of
Theory Construction
Theory Structure

**Formal Disciplines**
Formal Sciences
Game Theory

**Computer Science**
Artificial Intelligence
Big Data
Bioinformatics
Biostatistics
Church–Turing Thesis
Complex Systems
Cybernetics, 20th Century
Informatics
Information Theory
Information Theory, Historical Background
Software Engineering
Statistical Inference, Bayesian
Statistical Inference, Frequentist
Statistics
Statistics, Completeness in
Systems Science

**Logic and Mathematics**
Abduction
Abstraction
Analysis
Axiom Schema
Axiomatic Theory
Category Theory
Church–Turing Thesis
Communication Theory, Technical
  Overview
Concept
Cybernetics, 20th Century
Deduction
Generalization
Geometry, Classical
Geometry, Non-Euclidean
Gödel’s Incompleteness Theorems
Induction
Inference
Intuitionism in Logic and Mathematics
Justification
Knowledge
Linguistics, Contemporary
Linguistics, Historical
Logic, Formal and Informal
Logic, Inductive
Logic and Language
Logical Theory
Mathematics, 19th Century
Mathematics, 20th Century
Mathematics, Antiquity
Mathematics, Enlightenment
Mathematics, Middle Ages
Mathematics, Renaissance
Paraconsistency
Paradoxes
Perturbation Theory
Rational Mechanics
Realism in Mathematics
Reasoning
Refutation
Relative Consistency
Semantics (Introduction to Theory)
Semantics (Scientific and Empirical)
Set Theory
Soundness
Statistics
Syntax (Introduction to Theory)
Syntax (Scientific and Empirical)
Understanding

**Empirical Disciplines**
Physical Theory

**Biological Science**
Biochemistry, 19th Century
Biochemistry, 20th Century
Biochemistry, Contemporary
Bioinformatics
Biological Science
Biophysics, 19th Century
Biophysics, 20th Century
Biophysics, Contemporary
Biostatistics
Biotechnology
Cell Theory
Complementary Medicine
Developmental Systems Theory
Environmental Studies
Evolutionary Psychology
Game Theory
Genetic Drift
Germ Theory
Health Care Science
Infectious Disease Studies
Life Sciences, Contemporary
Medicine, 19th Century
Medicine, 20th Century
Medicine, Antiquity
Medicine, Contemporary
Medicine, Enlightenment
Medicine, Middle Ages
Medicine, Renaissance
Natural Selection
Neuroscience
Punctuated Equilibrium
Vitalism

Chemistry
Biochemistry, 19th Century
Biochemistry, 20th Century
Biochemistry, Contemporary
Chemistry

Cognitive Sciences
Artificial Intelligence
Belief Revision
Big Data
Biopsychosocial Model
Cognitive Science
Conceptual Blending
Evolutionary Psychology
Linguistic Frameworks
Linguistics, Contemporary
Linguistics, Historical
Mental Models
Neuroscience
Philosophy of Mind
Semantics (Introduction to Theory)
Semantics (Scientific and Empirical)
Syntax (Introduction to Theory)
Syntax (Scientific and Empirical)

Earth and Space Sciences
Climate Science
Cosmology
Environmental Studies
Geology
Natural Resources
Plate Tectonics

Engineering
Big Data

Bioinformatics
Communication Theory, Technical
Overview
Complex Systems
Cybernetics, 20th Century
Engineering, Contemporary
Engineering, History of Informatics
Information Theory
Modeling
Perturbation Theory
Software Engineering
Statistics

Physics
Biophysics, 19th Century
Biophysics, 20th Century
Biophysics, Contemporary
Complex Systems
Cosmology
Environmental Studies
Geophysics
Information Theory
Kinetic (Molecular) Theory
Physical Theory
Physics, 19th Century
Physics, 20th Century
Physics, Antiquity
Physics, Contemporary
Physics, Enlightenment
Physics, Gravitational Theory
Physics, Middle Ages
Physics, Quantum Theory
Physics, Renaissance
Physics, Solid-State
Physics, Thermodynamics
Plate Tectonics
Rational Mechanics
Systems Science

Technology
Artificial Intelligence
Cybernetics, 20th Century
Engineering, Contemporary
Engineering, History of Health Care Science
Informatics
Modeling
Nanotechnology
Software Engineering
About the Editor

James Mattingly is Associate Professor of Philosophy at Georgetown University. Originally from the Silicon Valley in California, he studied Great Books at St. John’s College in Annapolis, Maryland, and physics at University of California, Santa Cruz. He then returned to a study of the history and philosophy of science at Indiana University, where he received his PhD in 2002. Shortly before that, he was appointed assistant professor in the Georgetown University Department of Philosophy, where he has been ever since. His research is primarily in philosophy of science. He spends his efforts there about equally between general issues involving conceptual change in the sciences, the epistemology of science, the nature of scientific theories, scientific experiments, and scientific explanation on the one hand, and issues more specific to philosophy of physics on the other, including quantum gravity, general relativity, black holes and singularities, gauge theories, thermodynamics, and electrodynamics. He also has research interests in early modern philosophy, the foundations of logic and mathematics, and the history of logical empiricism and other movements that attempted to come to grips with the profound conceptual reorientation made necessary by the revolutionary changes in science at the turn of the 20th century. He has written and lectured extensively on scientific theories, epistemology of science, the nature of scientific experimentation, and the foundations of physics. He is the author of Information and Experimental Knowledge, published in 2021 by The University of Chicago Press.
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<thead>
<tr>
<th>Contributor</th>
<th>Institution</th>
</tr>
</thead>
<tbody>
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<td>Nipissing University</td>
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<td>The University of Bristol</td>
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<td>Nigeria Police Academy</td>
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<td>University of Copenhagen</td>
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<td>University of Iowa</td>
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<td>Marc Lange</td>
<td>University of North Carolina at Chapel Hill</td>
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<td>Richard Leo Lanigan</td>
<td>International Communicology Institute</td>
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<td>Virginia Tech</td>
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<td>Luca Mari</td>
<td>Università Càattaneo LIUC</td>
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<tr>
<td>Owen J. E. Maroney</td>
<td>Independent Scholar</td>
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<tr>
<td>Craig E. Mattson</td>
<td>Trinity Christian College</td>
</tr>
<tr>
<td>Mandy M. McBroom</td>
<td>Independent Scholar</td>
</tr>
<tr>
<td>Trudy Mercadal</td>
<td>Florida Atlantic University</td>
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<tr>
<td>Daniele Molinini</td>
<td>University of Lisbon</td>
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<tr>
<td>Katie Moss</td>
<td>Independent Scholar</td>
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<td>Roman Murawski</td>
<td>Adam Mickiewicz University</td>
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<td>Northwest Missouri State University</td>
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<td>Mariam Orkodashvili</td>
<td>Vanderbilt University</td>
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<td>Asil Ali Ozdogru</td>
<td>Uşküdar University</td>
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<td>University of Calcutta</td>
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<td>William M. Peaster</td>
<td>Independent Scholar</td>
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<tr>
<td>Judy Pelham</td>
<td>York University</td>
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<tr>
<td>Pablo A. Pellegrini</td>
<td>CONICET/National University of Quilmes</td>
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<tr>
<td>Michelle E. Pence</td>
<td>The University of Texas of the Permian Basin</td>
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<td>Nuria Perez-Perez</td>
<td>University of Pompeu Fabra</td>
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<td>Lakehead University</td>
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<td>Ole Ravn</td>
<td>Aalborg University</td>
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<td>Leslie J. Reynard</td>
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<td>Institute for Futures Studies</td>
</tr>
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<td>Joseph C. Rumenapp</td>
<td>St. John’s University</td>
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<td>Alexander Ruser</td>
<td>University of Agder</td>
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<td>Johns Hopkins University</td>
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<tr>
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<td>Østfold University College</td>
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<tr>
<td>Rodolfo Sarsfield</td>
<td>Autonomous University of Queretaro</td>
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<td>Manchester School of Architecture</td>
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<td>James A. Shapiro</td>
<td>University of Chicago</td>
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<td>Mark. D. Sherry</td>
<td>University of Toledo</td>
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<td>Robert Sinclair</td>
<td>Soka University</td>
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<tr>
<td>Mo E. Snyder</td>
<td>Acadia University</td>
</tr>
<tr>
<td>Aris Spanos</td>
<td>Virginia Tech</td>
</tr>
<tr>
<td>Jan Sprenger</td>
<td>University of Turin</td>
</tr>
</tbody>
</table>
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Introduction

The word “theory” has fascinating origins. In ancient Greek, the primary meaning of the word “θεωρία” (theory) seems to have been “looking at, viewing, beholding”. It also referred to ambassadors sent out to observe the oracle, or, on other occasions, the Olympic games. A variation of the word, theorem, can refer to the results of some science or technical discipline (what we might think of as engineering), and this is the word that Euclid uses to refer to the things that he proves in the Elements, our first systematic geometry book. In those cases, the theorems, or the things observed using the discipline, were tightly linked to the act of showing and seeing, to making plain. Today we might refer to, say, number theory and some of the things that we discover or prove or explain using number theory as its theorems. While “theory” is often associated with abstraction, with complication, with abstruseness it is grounded in the concrete, observable, repeatable results of the crafts, mathematics, and science.

The word “theory” is also, ironically, tightly linked equally to certainty and to pure speculation. On the one hand, in the popular imagination, theory seems sometimes associated to, say, the quantum theory, or the theory of relativity, two disciplines that have achieved unprecedented accuracy and experimental confirmation in the century since they were first formulated. On the other hand, it is common to hear, in response to a claim about the origin of various species on the earth, that natural selection is only a theory. Generally, people who study scientific theories insist, and rightly so, that speculation ungrounded in prior disciplinary work and without strong observational support does not merit being called “theory.” Theories are generally well-supported explanatory systems that organize the understanding of some discipline or sector of it. While novel theories are propounded in order to try to explain puzzling or novel data and are not accepted until they have themselves been tested, when used to make assertions about the world and what we can expect to see, a theory typically has already been stringently tested and found to be observationally adequate.

Why an Encyclopedia of Theory, and Why STEM?

A collection of articles about scientific theory in its various aspects seems worthwhile for a number of reasons. First and foremost our scientific theories are the vehicles of what we know where the results and understanding of various disciplines are codified so that they can be transmitted, taught to new members of the discipline, and integrated with the results of other disciplines. They are, relatedly, tools for understanding and controlling the phenomena studied in a discipline. This is enough to make the theories themselves of significant and enduring interest. But in addition to the multitude of individual theories in the various STEM disciplines, there is also the matter of theory as itself a topic worthy of study.

My own academic discipline is neither science, nor technology, nor engineering, nor mathematics. Instead, it is philosophy of science. Philosophers of science do make contributions, sometimes, to science (or technology, or engineering, or mathematics) but that is not what their main focus is. Their main focus is to understand science and related disciplines as themselves objects of study. They ask: How does physics relate to chemistry? What do biologists mean when they use the expression “species”? Do experiments in social science give secure knowledge? Beyond such discipline specific questions though philosophers of science are


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interested in big questions about the nature of scientific inquiry, and one of the main foci of philosophy of science has long been the theories that are produced and used in the sciences. What kind of thing is a theory? Is it a collection of true remarks about some field? Is it a calculus for predicting things? Is it a vehicle for understanding the subject matter of some discipline? Or is it something else altogether? These are important concerns to philosophers. But philosophers’ concerns are not always the concerns of scientists, and are rarely those of students. We are often seen as out of touch with the real, grounded, day to day understanding of things and we are seen as nit-picking to little effect. Happily, however, philosophers are not the only ones who ask and answer such questions. So too do sociologists of science, scientific practitioners themselves, engineers, mathematicians, logicians, and so on. These have joined in with philosophers to contribute to this encyclopedia. What you will find across the many entries in this encyclopedia is a broad diversity of disciplinary background, but it is a diversity that displays unity of purpose if not of method or disciplinary assumptions. These many perspectives highlight just some of the important ways of understanding theory in philosophy and the sciences and make it clear that there are a number of roads into an understanding of theory.

As noted earlier, this encyclopedia is designed to support the study of theory in itself as well as the study of specific theories. The reasons for this are many. First, the scope of the encyclopedia allows for highlighting the vast range of topics that fall under the concept and also highlight key developments of theory along with key uses in various STEM disciplines. Next, putting things together this way can help to normalize the proper sense of “theory” as it is used in the sciences, and allow for nuanced discussion of the limits and scope of the claims made in the sciences without falling into bimodal habits of excessive deference or thoughtless dismissal. The concreteness of the specific disciplines’ theories and the variety of tools and techniques that arise in one and find application in another provides an interesting contrast. This contrast can help to illustrate the fruitfulness over time of feedback between study of theory and development of theory as an object of use in STEM disciplines, and transfer of innovations in theory between disciplines. Finally, this encyclopedia, covering as it does such a range of topics displays the importance of interactions and feedback between theory as it used and theory as it is . . . well . . . theorized.

The encyclopedia is an attempt to shed some light on the nature of theories in the STEM disciplines. I have talked about reasons to focus on theory. But why focus on STEM? First, it may not seem to be a good category in some respects, either as an academic umbrella term or as a unified object of study. The classification of STEM fields under an umbrella term that joins the abstract pursuits of modern sciences like quantum theory and mathematics together with the concrete and practical practices of technological production and engineering may seem like a novelty thought up by ambitious administrators trying to figure out where best to direct institutional efforts and funding at fields that are likely to return measurable fruits. While there is some truth to that, it is almost precisely what Robert Boyle and folks like him were trying to do when they instituted the practice of modern science. Out of fractured and individualized practices and closely guarded techniques and knowledge developed in secret, Boyle attempted to produce an open society of inquiry, grounded in observation and reason, dedicated to improving human lives.

In any case, STEM is a term of current use, and moreover can be useful here as a demarcation criterion between a number of ways “theory” can be employed. In some academic disciplines, theory has more to do with providing an interpretation of various kinds of activity or features of the world so that some new phenomena can be revealed. Maybe an analysis of various patterns of speech in a community can be seen to reveal important background assumptions of that community, and sometimes “ theorizing” is a way of capturing the activity involved in making it possible to be aware of those assumptions. This use of “theory” has its own life and vast disciplinary context, one that is importantly different from what will be found in these pages. Here the use of “theory,” although broad, is constrained in different ways from much of what is found in other disciplines. It would be silly to say that one use is correct and the other not, and it would also be silly to suppose that there is nothing to be learned about one way of
deploying the concept theory from studying other ways, for there will be important points of contact. However, STEM is a natural domain of application for one way of thinking about the concept, and there is utility for students in fields broadly under this umbrella, or who are trying to learn about topics related to those fields, to have a ready and broadly unified resource for orienting themselves to the way theory is used and developed in those fields. And as an aside it is the one that hews most closely to my own disciplinary competence.

The Organization and Rationale of the Encyclopedia

My main aims for the encyclopedia are two. On the one hand, I want users to find here examples of the various technical and conceptual components of what it is to be a theory, in general terms and not merely as these theories appear in and are used by various STEM focused disciplines as a way of organizing, grasping, making use of, critiquing, and expanding our knowledge of some subject matter. To reflect that part of the aim included here are a number of entries that are concerned with theory itself, in some way detached from any particular subject matter concerning which one might construct or employ a theory. On the other hand, I want users to see the way that various STEM disciplines theorize about their subject matters, both how they make use of existing understanding of what theories are and how they function and how the individual disciplines, by attempting to make theories adequate to the peculiarities of their subject matter, fruitfully extend the very meaning of what it is to be a theory. While these subject matter entries will contain framing material about the theory of their subject matter, their main task will be to illuminate what role theory plays in the discipline and what insights into the nature of theory follows from that illumination.

The entries for the Encyclopedia of Theory in STEM range widely. There are 173 entries comprising nearly 625,000 words of text in entries ranging from 1,500 to 7,000 words. The entries have been grouped into 13 categories: there are four broad categories with several further categories grouped under two of them. The categories and their respective entries form the Reader’s Guide, which follows the List of Entries in the front matter of the encyclopedia. The categories are also listed below. I have chosen to group according to discipline, widely understood, as the most perspicuous way of navigating the topics of the encyclopedia. There is inevitable categorical overlap in a number of disciplines, and some inevitable awkward fits given our scope constraints, and the fact that some of the disciplines considered here are generally thought to be situated in non-STEM-covering disciplines, but seemed necessary to include for reasons of coherence.

The first division in the structure of the encyclopedia is between general matters having to do with science and theory and specific matters having to do with particular disciplines within STEM.

I. General Theory of Science: Here you will find entries having to do with the nature of science, including its authoritativeness, the way its claims are tested, in short the basic conceptual features of the scientific enterprise as a whole.

II. Nature and Structure of Theories: Here the discussion remains general and at a high level of abstraction but the focus is more specifically on the nature of scientific theory. What kind of thing is a theory? How is it connected to other things we do in the sciences? What have theorists about theories learned over the last century from science and from analysis of science, and what has science itself learned from such theorizing.

Turning to the more specific disciplines we see the second division, between disciplines more on the empirical side of things and those on the formal side. Here are found discussions both of matters having to do specifically with the day-to-day features of these disciplines and of general issues that frame and clarify their scope and limits. While these entries give accessible overviews of the subject matter of the disciplines, those overviews are no substitute for extensive study of the disciplines. Instead just enough is presented to make it possible to understand the role of theory in these disciplines.

III. Formal Disciplines: These disciplines are less grounded in empirical data and more focused on concepts. But that is not to say that empirical matters can be entirely neglected. Even in logic and
mathematics, but especially in computer science questions of resources and the role of complexity make it impossible to fully detach oneself from facts about the world. Even so entries here are more focused on structural features of theories, in addition to specific disciplinary matters. This topic is further divided into:

1. Computer Science
2. Logic and Mathematics

IV. Empirical Disciplines: The empirical disciplines as well are not monolithically empirical. Constraints from the nature of mathematics and logic have an impact on the kinds of theory that are possible here. But these entries are more directed to specific developments in observationally testable domains as well as to the connection between theoretical and observational features. This topic is further divided into:

1. Biological Science
2. Chemistry
3. Cognitive Sciences
4. Earth and Space Sciences
5. Engineering
6. Physics
7. Technology

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James Mattingly