

## Contents

	Preface	X111
	Organisation of the book	XV
	Acknowledgements	xvii
	Preview	
Session 1	Galileo and multiplication of objects	3
	1 Introduction	3
	2 Galileo and the flight of a bird	3
	3 Other examples of multiplication of objects	7
	Part I The category of sets	
Article I	Sets, maps, composition	13
	1 Guide	20
Summary:	Definition of category	21
Session 2	Sets, maps, and composition	22
	1 Review of Article I	22
	2 An example of different rules for a map	27
	3 External diagrams	28
	4 Problems on the number of maps from one set to another	29
Session 3	Composing maps and counting maps	31
	Part II The algebra of composition	
Article II	Isomorphisms	39
	1 Isomorphisms	39
	2 General division problems: Determination and choice	45
	3 Retractions, sections, and idempotents	49
	4 Isomorphisms and automorphisms	54
	5 Guide	58
Summary:	Special properties a map may have	59



viii		Contents
Session 4	Division of maps: Isomorphisms	60
	1 Division of maps versus division of numbers	60
	2 Inverses versus reciprocals	61
	3 Isomorphisms as 'divisors'	63
	4 A small zoo of isomorphisms in other categories	64
Session 5	Division of maps: Sections and retractions	68
	1 Determination problems	68
	2 A special case: Constant maps	70
	3 Choice problems	71
	4 Two special cases of division: Sections and retractions	72
	5 Stacking or sorting	74
	6 Stacking in a Chinese restaurant	76
Session 6	Two general aspects or uses of maps	81
	1 Sorting of the domain by a property	81
	2 Naming or sampling of the codomain	82
	3 Philosophical explanation of the two aspects	84
Session 7	Isomorphisms and coordinates	86
	1 One use of isomorphisms: Coordinate systems	86
	2 Two abuses of isomorphisms	89
Session 8	Pictures of a map making its features evident	91
Session 9	Retracts and idempotents	99
	1 Retracts and comparisons	99
	2 Idempotents as records of retracts	100
	3 A puzzle	102
	4 Three kinds of retract problems	103
	5 Comparing infinite sets	106
Quiz	a 1 11	108
	te the quiz problems	109
•	n of opposed maps	114
• . •	uiz on pairs of 'opposed' maps	116 117
Summary: Review of 'I	On the equation $p \circ j = 1_A$	118
Test 1	-words	119
1030 1		117
Session 10	Brouwer's theorems	120
	1 Balls, spheres, fixed points, and retractions	120
	2 Digression on the contrapositive rule	124
	3 Brouwer's proof	124



Contents		ix
	4 Relation between fixed point and retraction theorems 5 How to understand a proof:	126
	The objectification and 'mapification' of concepts	127
	6 The eye of the storm	130
	7 Using maps to formulate guesses	131
	Part III Categories of structured sets	
Article III	Examples of categories	135
	1 The category $S^{\bigcirc}$ of endomaps of sets	136
	2 Typical applications of $S^{\bigcirc}$	137
	3 Two subcategories of <b>S</b> <sup>©</sup>	138
	4 Categories of endomaps	138
	5 Irreflexive graphs	141
	6 Endomaps as special graphs	143
	7 The simpler category $\mathbf{S}^{\downarrow}$ : Objects are just maps of sets	144
	8 Reflexive graphs	145
	9 Summary of the examples and their general significance	146
	10 Retractions and injectivity	146
	11 Types of structure	149
	12 Guide	151
Session 11	Ascending to categories of richer structures	152
	1 A category of richer structures: Endomaps of sets	152
	2 Two subcategories: Idempotents and automorphisms	155
	3 The category of graphs	156
Session 12	Categories of diagrams	161
	1 Dynamical systems or automata	161
	2 Family trees	162
	3 Dynamical systems revisited	163
Session 13	Monoids	166
Session 14	Maps preserve positive properties	170
	1 Positive properties versus negative properties	173
Session 15	Objectification of properties in dynamical systems	175
	1 Structure-preserving maps from a cycle to another	
	endomap	173
	2 Naming elements that have a given period by maps	170
	3 Naming arbitrary elements	17
	4 The philosophical role of N	180
	5 Presentations of dynamical systems	182



X		Contents
Session 16	Idempotents, involutions, and graphs	187
	1 Solving exercises on idempotents and involutions	187
	2 Solving exercises on maps of graphs	189
Session 17	Some uses of graphs	196
	1 Paths	196
	2 Graphs as diagram shapes	200
	3 Commuting diagrams	201
	4 Is a diagram a map?	203
Test 2		204
Session 18	Review of Test 2	205
	Part IV Elementary universal mapping propert	ies
Article IV	Universal mapping properties	213
	1 Terminal objects	213
	2 Separating	215
	3 Initial object	215
	4 Products	216
	5 Commutative, associative, and identity laws for	
	multiplication of objects	220
	6 Sums	222
	7 Distributive laws	222
	8 Guide	223
Session 19	Terminal objects	225
Session 20	Points of an object	230
Session 21	Products in categories	236
Session 22	Universal mapping properties and incidence relations	245
	1 A special property of the category of sets	245
	2 A similar property in the category of endomaps	
	of sets	246
	3 Incidence relations	249
	4 Basic figure-types, singular figures, and incidence,	
	in the category of graphs	250
Session 23	More on universal mapping properties	254
	1 A category of pairs of maps	255
	2 How to calculate products	256



Contents		xi
Session 24	Uniqueness of products and definition of sum	261
	1 The terminal object as an identity for multiplication	261
	2 The uniqueness theorem for products	263
	3 Sum of two objects in a category	265
Session 25	Labelings and products of graphs	269
	1 Detecting the structure of a graph by means of labelings	270
	2 Calculating the graphs $A \times Y$	273
	3 The distributive law	275
Session 26	Distributive categories and linear categories	276
	1 The standard map	
	$A \times B_1 + A \times B_2 \longrightarrow A \times (B_1 + B_2)$	276
	2 Matrix multiplication in linear categories	279
	3 Sum of maps in a linear category	279
	4 The associative law for sums and products	281
Session 27	Examples of universal constructions	284
	1 Universal constructions	284
	2 Can objects have negatives?	287
	3 Idempotent objects	289
	4 Solving equations and picturing maps	292
Session 28	The category of pointed sets	295
	1 An example of a non-distributive category	295
Test 3		299
Test 4		300
Test 5		301
Session 29	Binary operations and diagonal arguments	302
	1 Binary operations and actions	302
	2 Cantor's diagonal argument	303
	Part V Higher universal mapping properties	
Article V	Map objects	313
	1 Definition of map object	313
	2 Distributivity	315
	3 Map objects and the Diagonal Argument	316
	4 Universal properties and 'observables'	316
	5 Guide	319
Session 30	Exponentiation	320
	1 Map objects, or function spaces	320



xii		Contents
	2 A fundamental example of the transformation of map objects	323
	<ul><li>3 Laws of exponents</li><li>4 The distributive law in cartesian closed categories</li></ul>	324 327
Session 31	Map object versus product  1 Definition of map object versus definition of product  2 Calculating map objects	328 329 331
Article VI	The contravariant parts functor  1 Parts and stable conditions  2 Inverse Images and Truth	335 335 336
Session 32	Subobject, logic, and truth  Subobjects  Truth  The truth value object	339 339 342 344
Session 33	Parts of an object: Toposes 1 Parts and inclusions 2 Toposes and logic	348 348 352
Article VII	The Connected Components Functor  Connectedness versus discreteness  The points functor parallel to the components functor  methods for the topos of right actions of a monoid	358 358 359 360
Session 34	Group theory and the number of types of connected objects	362
Session 35	Constants, codiscrete objects, and many connected objects  Constants and codiscrete objects  Monoids with at least two constants	366 366 367
Appendices Appendix I	Geometery of figures and algebra of functions 1 Functors 2 Geometry of figures and algebra of functions as categories	368 369 369
Appendix III	themselves Adjoint functors with examples from graphs and dynamical sys The emergence of category theory within mathematics Annotated Bibliography	370 stems 372 378 381
Index		385