Science Teaching and Development of Thinking

Anton E Lawson Arizona State University





CONTENTS

PREFACE

CHAPTER 1 **TEACHING AND THE NATURE OF SCIENCE Educational Purpose 1** The Nature of Scientific Thinking: A Look at the Work of an Ethologist 5 Creating Hypotheses 6 Testing Hypotheses 8 Why Hypotheses Are Neither Proven nor Disproven 11 The Origin and Nature of Theories: A Look at the Work of Charles Darwin 13 The Use of Analogy 16 The Nature of Theories 17 How Are Theories Tested? The Case of Spontaneous Generation 23 Science and Religion 27 The Role of Observation in Science: The "Construction" of Oxygen 28

xvii

1

VII

CHAPTER 2 PATTERNS OF THINKING BY SCIENTISTS AND BY ADOLESCENTS

Homing Behavior in Silver Salmon 43

Raising a Causal Question 43 Creating Hypotheses and Combinatorial Thinking 44 Generating Predictions 45 Identifying and Controlling Variables 45 Drawing Conclusions 46 Probabilistic and Correlational Thinking 46

Creative and Critical Thinking Skills 49 The Nature of Adolescent Thinking 53

The Mealworm Puzzle 53 The Volume Puzzle 55 The Frog Puzzle 58

Empirical-Inductive and Hypothetical-Deductive Thinking Patterns 60

Empirical-Inductive Thinking Patterns 60 Hypothetical-Deductive Thinking Patterns 61 Analysis of Student Responses 62

Summary 65

CHAPTER 3 SCIENTIFIC KNOWLEDGE: ITS CONSTRUCTION AND DEVELOPMENT

The Nature of Declarative Knowledge 69 Types of Concepts 70 Types of Conceptual Systems 73 Mental Structures and the Process of Self-Regulation 74 The Pattern of Knowledge Construction 75 The Role of Mental Structures 76 Additional Examples of Self-Regulation 78 Disrupting Children's Spontaneous Attempts at Self-Regulation 82 Three Basic Mental Abilities and Self-Regulation 83 How Do Thinking Patterns Function in Adult Thinking? 83 Contributing Factors in Self-Regulation 85 How Are Descriptive Concepts Constructed? 88

100

The Role of Chunking in Higher-Order Concept Construction 91 How Are Theoretical Concepts Constructed? 91 Practice in Classifying Science Concepts 96

CHAPTER 4 STAGES IN THE DEVELOPMENT OF PROCEDURAL KNOWLEDGE

Piaget's Theory 101

The Four Card Task and Hypothetical-Deductive Thought 103 Algebra and Hypothetical-Deductive Thought 105 A New View of Stage Theory 106

Stage 1 (Birth to 18 Months) 107 Stage 2 (18 Months to 7 Years) 107 Stage 3 (7 Years to Early Adolescence) 110 Stage 4 (Early Adolescence and Older) 111

The Relationship Between Procedural and Declarative Knowledge: A Closer Look 112

A Return to the Mellinarks 117

How Does Hypothetical-Deductive Thought Develop? 121 Developing the Procedure of Controlled Experimentation 124

Session 1 125 Session 2 127 Session 3 127 Session 4 128

CHAPTER 5 THE LEARNING CYCLE

132

Essential Elements of Science Instruction 133 The Learning Cycle 134 Three Types of Learning Cycles 139 Descriptive Learning Cycles 142

Empirical-Abductive Learning Cycles 142 Hypothetical-Deductive Learning Cycles 143

Learning Cycles as Different Phases of Doing Science 147 A Note on Creativity 149 A Note on Intelligence and Achievement 150

Historical Perspective: Origins of the Learning Cycle 155

The Origins of Inquiry-Oriented Instruction 155 Origins in the SCIS Program 158 Origins in Biology Education 160 Changes in Names: The Phases of the Learning Cycle 161

The Learning Cycle in the BSCS Program 162 The Learning Cycle in Driver's Conceptual Change Model 162 Key Postulates 162 Selecting Appropriate Explorations 169

General Science 169 Biology 171 Chemistry 173 Physics 175

CHAPTER 6 CHARACTERISTICS OF EFFECTIVE SCIENCE INSTRUCTION

Lesson Characteristics 178 Characteristics of Student Behavior 180 Characteristics of Teacher Behavior 181 Characteristics of Effective Questioning 182 Example Lessons 184 Keeping Inquiry Going and "Covering" Content 200 Helping Students Create Hypotheses 201 Correcting "Wrong" Conclusions 202 Classroom Control, Motivation, and Seating Arrangements 203 Covering Content 204 Scheduling Learning Cycles 204

CHAPTER 7 WHY DON'T MORE TEACHERS USE INQUIRY-ORIENTED METHODS?

Resistance to Inquiry 211

Time and Energy 211 Too Slow 213 Reading Too Difficult 214 Risk Too High 218 Tracking 219 Student Immaturity 220 177

Teaching Habits 221 Sequential Text 221 Discomfort for Teachers and Students 222 Too Expensive 223

Conclusion 224

CHAPTER 8 PRINCIPLES OF CURRICULUM DEVELOPMENT AND IMPLEMENTATION

226

Curriculum Principles: Concept Organization and Presentation 227 The Undifferentiated Whole 228

Examples of Teaching Conceptual Systems 233

The Ecosystem 233 Evolution and Natural Selection 238

Curricular Principles for the Development of Thinking Skills 247

Self-Regulation 247 Independent Investigations 248 Historical Model 249 Comparing Conceptual Systems 249

Textbook Use and Selection 250 Using Field Trips to Provoke Self-Regulation 254 An Example of Student Field Work 256 Comments and Ouestions About Student Work 260

CHAPTER 9 STUDENT ASSESSMENT

261

Classifying Test Items 262 Biology 262 Geology 264 Chemistry 266 Physics 268

Empirical-Inductive and Hypothetical-Deductive Test Items 270 Using Test Items to Encourage Self-Regulation 272 Using Homework Problems to Encourage Self-Regulation 274 What Is Wrong with Typical Homework Problems? 275 How to Encourage Self-Regulation 276 Examples of Physical Science Homework Problems 278 Examples of Biological Science Homework Problems 283

Written Work 287

Lab Report Guidelines 288 The One-Page Lab Report 289 Science Fair Projects 290 Portfolio Assessment 295

CHAPTER 10 DIRECTIONS FOR FUTURE RESEARCH AND DEVELOPMENT

Conceptions and Misconceptions 301 Motivation and Assessment 303 Cooperative Learning 303 Sequencing and Selecting Content 304 The Role of Analogy 306 Retention and Transfer of Thinking Skills 307 Teaching Content Versus Process 308 Textbooks 309 New Technologies 310 Teacher Education and Professional Growth 310 Other Currently Popular Methods 312 Project 2061 313 Integrating Social and Technological Issues 314 Testing 316 Theoretical Issues and a Problem with "Social" Constructivism 317 Conclusion 319

CHAPTER 11 NEUROLOGICAL MODELS OF SELF-REGULATION AND INSTRUCTIONAL METHODS

323

300

Basic Neurological Principles 324 General Brain Anatomy 324 Neuronal Signals 326

General Principles of Network Modeling 327 Equations of Variable Interactions 328

Learning in a Simple Circuit: Classical Conditioning 330 Learning in Humans: A More Complex Network 331 The Basic Pattern of Knowledge Construction 331 The Neural Network 333

The Rebound from Hunger to Satisfaction 334
Stopping Feeding Behavior Resulting from Frustration 334
Match and Mismatch of Input with Expectations:
Adaptive Resonance 335

Extension of Network Characteristics to Higher Levels of Learning 338

Initiating and Terminating Problem-Solving Behavior 340 Terminating the Additive Strategy Because of Contradiction 341

Orienting Arousal and the Search for a New Strategy 342 Feedback and Internal Monitoring of Problem Solving 343

Instructional Implications 344

Self-Regulation, Constructivism, and the Learning Paradox 346

Emergent Properties in the Natural Sciences 347 Emergent Properties in Cognition 348 A Return to Classical Conditioning 349

CHAPTER 12 THE ROLE OF LOGICAL AND ANALOGICAL THINKING IN KNOWLEDGE CONSTRUCTION

Role of Logic 352

Two Common Forms of Logic 353 The Multiple-Hypothesis Theory of Hypothetical-Deductive Thought: Key Elements 361 Testing the Alternatives 362 Conclusions and Recommendations 365

A Neurological Explanation of Memory and Analogical Thinking 367

Adaptive Resonance 369 Outstars and Instars: Fundamental Units 370 The Neural Basis for Analogy 374 An Emergent, Self-Organizing Control System 376 A Return to the Japanese Classroom 380 Summary 381

Integrating Philosophy, Neural Modeling, Scientific Insight, and Instruction 382

.

APPENDIX A	THE CENTRAL PURPOSE OF AMERICAN EDUCATION Educational Policies Commission	387
APPENDIX B	THE METHOD OF MULTIPLE WORKING HYPOTHESES T. C. Chamberlain	398
APPENDIX C	WHAT IS SCIENCE? R. P. Feynmen	408
APPENDIX D	RESEARCH ON THE LEARNING CYCLE A. E. Lawson, M. R. Abraham, and J. W. Renner	418
APPENDIX E	TEACHING AND THE EXPANDING KNOWLEDGE A. Szent-Gyorgyi	432
APPENDIX F	CLASSROOM TEST OF SCIENTIFIC REASONING	436
APPENDIX G	LEARNING CYCLES	446
	Learning Cycle 1: Is Water a "Pure" Substance? 447	
. *	Learning Cycle 2: What Happens When Food Coloring and Detergent Are Put in Milk? 460	
	Learning Cycle 3: How Were Alien Monoliths Sorted? 471	
	Learning Cycle 4: What Is Energy? 480	
	Learning Cycle 5: What Causes Molecules to Move? 492	
	Learning Cycle 5: What Causes Molecules to Move? 492 Learning Cycle 6: How Does Cell Structure Relate to Function? 503	
	Learning Cycle 6: How Does Cell Structure	
	Learning Cycle 6: How Does Cell Structure Relate to Function? 503 Learning Cycle 7: How Do Multicellular	
	Learning Cycle 6: How Does Cell Structure Relate to Function? 503 Learning Cycle 7: How Do Multicellular Organisms Grow? 520 Learning Cycle 8: What Happens to Molecules During	

Learning Cycle 10: Why Do Liquids Evaporate at Different Rates? 544

Learning Cycle 11: What Changes Have Occurred in Organisms Through Time? 556

REFERENCES

573

INDEX