

APPLYING COGNITIVE SCIENCE TO EDUCATION

Thinking and Learning in Scientific and Other Complex Domains

FREDERICK REIF

**A Bradford Book
The MIT Press
Cambridge, Massachusetts
London, England**

© 2008 Massachusetts Institute of Technology

All rights reserved. No part of this book may be reproduced in any form by any electronic or mechanical means (including photocopying, recording, or information storage and retrieval) without permission in writing from the publisher.

MIT Press books may be purchased at special quantity discounts for business or sales promotional use. For information, please e-mail <special_sales@mitpress.mit.edu> or write to Special Sales Department, The MIT Press, 55 Hayward Street, Cambridge, MA 02142.

This book was set in Stone Serif and Stone Sans on 3B2 by Asco Typesetters, Hong Kong and was printed and bound in the United States of America.

Library of Congress Cataloging-in-Publication Data

Reif, F. (Frederick), 1927–

Applying cognitive science to education : thinking and learning in scientific and other complex domains / Frederick Reif.

p. cm.

Includes bibliographical references and index.

ISBN 978-0-262-18263-8 (hardcover : alk. paper) 1. Cognitive learning.

2. Learning, Psychology of. 3. Cognitive science. 4. Education. I. Title.

LB1060.R423 2007

372.15'2—dc22

2007006486

10 9 8 7 6 5 4 3 2 1

Contents

Preface xiii

I BASIC ISSUES 1

1 Performance, Learning, and Teaching 3

- 1.1 Thinking about thinking 3
- 1.2 Basic issues 4
- 1.3 Importance of these issues 5
- 1.4 Structure of the book 8

2 Intellectual Performance 11

- 2.1 Description of performance 11
- 2.2 Performance in complex domains 13
- 2.3 Characteristics of good performance 15
- 2.4 Analysis of performance 18
- 2.5 Analysis of good performance 21
- 2.6 Comparisons and overview 23
- 2.7 Summary 26

II GOOD PERFORMANCE 27

II-A Usability 29

3 Important Kinds of Knowledge 31

- 3.1 Declarative and procedural knowledge 32
- 3.2 Comparative advantages and disadvantages 33
- 3.3 Uses of declarative and procedural knowledge 34
- 3.4 Condition-dependent knowledge 37
- 3.5 Educational implications 38
- 3.6 Summary 41

4	Specifying and Interpreting Concepts	43
4.1	Knowledge and concepts	44
4.2	Types of concepts	47
4.3	Kinds of concept specifications	51
4.4	Scientific importance of concept specifications	54
4.5	Educational implications	57
4.6	Summary	59
5	Interpreting Scientific Concepts	61
5.1	Students' interpretation of the concept <i>acceleration</i>	62
5.2	Motion and the concept of acceleration	66
5.3	Specification of acceleration	69
5.4	Causes of interpretation deficiencies	71
5.5	Requirements for usable concept knowledge	77
5.6	Educational implications	80
5.7	Summary	83
6	Managing Memory	85
6.1	Properties of human memory	86
6.2	Basic memory processes	88
6.3	Practical memory management	94
6.4	Educational implications	98
6.5	Summary	100
II-B	Effectiveness	101
7	Methods and Inferences	103
7.1	Methods and procedures	104
7.2	Specification of procedures	106
7.3	Making inferences	109
7.4	Educational implications	113
7.5	Summary	116
8	Describing Knowledge	119
8.1	Descriptions and their referents	120
8.2	Alternative descriptions	122
8.3	Characteristics of different descriptions	126
8.4	Complementary use of different descriptions	129
8.5	Educational implications	132
8.6	Summary	136
9	Organizing Knowledge	137
9.1	Importance of knowledge organization	138
9.2	Some forms of knowledge organization	139
9.3	Dealing with large amounts of knowledge	142

- 9.4 Knowledge elaboration 143
- 9.5 Hierarchical knowledge organization 145
- 9.6 Examples of hierarchical knowledge organizations 149
- 9.7 Educational implications 155
- 9.8 Summary 161

II-C Flexibility 163

10 Making Decisions 165

- 10.1 Importance of decision making 166
- 10.2 Kinds of decisions 168
- 10.3 Making complex decisions 170
- 10.4 More refined option assessments 173
- 10.5 Limitations of analytic decisions 177
- 10.6 Practical decision making 180
- 10.7 Decisions in scientific domains 183
- 10.8 Educational implications 185
- 10.9 Summary 187

11 Introduction to Problem Solving 189

- 11.1 Problem Characteristics 190
- 11.2 Challenges of improving problem solving 196
- 11.3 Educational implications 199
- 11.4 Summary 200

12 Systematic Problem Solving 201

- 12.1 A useful problem-solving strategy 201
- 12.2 Describing a problem 204
- 12.3 Analyzing a problem 207
- 12.4 Constructing a solution 210
- 12.5 Examples of solution constructions 214
- 12.6 Assessing a solution 221
- 12.7 Exploiting a solution 223
- 12.8 Educational implications 224
- 12.9 Summary 227

13 Dealing with Complex Problems 229

- 13.1 Managing complexity by task decomposition 229
- 13.2 Planning 231
- 13.3 Supportive knowledge 235
- 13.4 Helpful form of solution 237
- 13.5 Quantitative and qualitative problems 238
- 13.6 Writing as problem solving 243
- 13.7 Applying the problem-solving strategy to writing 244
- 13.8 Educational implications 249
- 13.9 Summary 252

II-D Efficiency 255**14 Efficiency and Compiled Knowledge 257**

- 14.1 Importance of efficiency 258
- 14.2 Compiling knowledge 260
- 14.3 Routine performance 261
- 14.4 Automatic performance 263
- 14.5 Benefits and dangers of efficient performance 266
- 14.6 Educational implications 267
- 14.7 Summary 269

II-E Reliability 271**15 Quality Assurance 273**

- 15.1 Ensuring good quality 274
- 15.2 Preventing defects 276
- 15.3 Assessing performance 278
- 15.4 Improving performance 280
- 15.5 Metacognition 281
- 15.6 Educational implications 282
- 15.7 Summary 284
- 15.8 Good performance and the instructional challenge 285

III PRIOR KNOWLEDGE 287**16 Unfamiliar Knowledge Domains 289**

- 16.1 Prior knowledge and new learning 290
- 16.2 Everyday and scientific domains 293
- 16.3 Contrasting scientific and everyday cognitions 297
- 16.4 Scientists' and students' conceptions of science 302
- 16.5 Educational implications 306
- 16.6 Summary 308

17 Naive Scientific Knowledge 311

- 17.1 Characteristics of naive scientific knowledge 312
- 17.2 Students' prior knowledge about science 314
- 17.3 Naive conceptions about motion 316
- 17.4 Naive notions about the causes of motion 319
- 17.5 Force as a cause of motion 322
- 17.6 Educational implications 327
- 17.7 Summary 332

IV LEARNING AND TEACHING 333**18 Developing Instruction 335**

- 18.1 Instructional development as a problem-solving task 335
- 18.2 Stages of instructional development 337
- 18.3 Overview of instructional development 339
- 18.4 Summary 342

19 Designing the Learning Process: Goals 343

- 19.1 Describing the learning problem 343
- 19.2 Analyzing the learning problem 347
- 19.3 Comparative analysis 354
- 19.4 Summary 355

20 Designing the Learning Process: Means 357

- 20.1 Decomposing and sequencing the learning process 357
- 20.2 Encoding new knowledge 360
- 20.3 Managing cognitive load 361
- 20.4 Exploiting useful organization 365
- 20.5 Ensuring the utility of acquired knowledge 372
- 20.6 Ensuring the reliability of acquired knowledge 373
- 20.7 Assessing a learning design 374
- 20.8 Achieving genuinely good performance 375
- 20.9 Summary 375

21 Producing Instruction to Foster Learning 377

- 21.1 Describing the instructional problem 377
- 21.2 Analyzing instructional needs 380
- 21.3 Helpful instructional interactions 381
- 21.4 Managing instruction 384
- 21.5 Learning by teaching 388
- 21.6 Assessing instruction 394
- 21.7 Summary 399

V IMPLEMENTING PRACTICAL INSTRUCTION 401**22 Traditional Instructional Methods 403**

- 22.1 The instructional delivery problem 403
- 22.2 Lectures 406
- 22.3 Textbooks 408
- 22.4 Homework assignments 409
- 22.5 Small instructional groups 411
- 22.6 Assessment of instructional delivery 412
- 22.7 Summary 415

23 Innovative Instructional Methods	417
23.1 Modified lecture forms	417
23.2 Cooperative learning	420
23.3 Packaged instruction	423
23.4 Technology-supported instruction	428
23.5 Potential benefits of educational technology	432
23.6 Summary	437
24 Some Educational Challenges	439
24.1 Providing more individual learning assistance	439
24.2 Teaching general thinking and learning skills	440
24.3 More scientific approaches to education	443
24.4 More significant educational role of universities	445
24.5 Summary	448
References	451
Index	465