Artificial Intelligence and Human Learning

INTELLIGENT COMPUTER-AIDED INSTRUCTION

edited by
John Self

CHAPMAN AND HALL COMPUTING

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LONDON NEW YORK
Chapman and Hall

First published in 1988 by
Chapman and Hall Ltd
11 New Fetter Lane, London EC4P 4EE
Published in the USA by
Chapman and Hall
29 West 35th Street, New York NY 10001

Printed in Great Britain by
J. W. Arrowsmith Ltd, Bristol

ISBN 0 412 16610 0 (hardback)
0 412 30130 X (paperback)

British Library Cataloguing in Publication Data

Artificial intelligence and human learning:
intelligent computer-aided instruction.—
(Chapman and Hall computing series).
1. Computer-assisted instruction
I. Self, John
371.3′9445 LB1028.5

ISBN 0-412-16610-0
ISBN 0-412-30130-X Pbk

Library of Congress Cataloging in Publication Data

Artificial intelligence and human learning.

Bibliography: p.
Includes index.
1. Artificial intelligence. 2. System design.
3. Computer-assisted instruction. I. Self, John.
Q335.A78719 1988 371.3′9445 87–11587

ISBN 0-412-16610-0
ISBN 0-412-30130-X (pbk.)

ARTIFICIAL INTELLIGENCE AND HUMAN LEARNING

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Preface

Artificial Intelligence (AI) is now recognized as one of the major scientific endeavours of the twentieth century. In the last few years there has been an extraordinary growth in the practical application of AI to many fields: expert systems in industry, natural language understanding systems, robotics, and so on. This growth has been fuelled by unprecedented support from American, European and Japanese governments.

At the same time, the education industry has had problems: dwindling public and government backing, pressure to provide more vocational training, demands for measures of teacher performance, difficulty in obtaining skilled staff, and the pace of technological change. It seems inevitable, therefore, that the new science of AI will be brought to bear on the problems of education.

If the reader has not winced at the crassness of this argument – which is, in essence, the official reason for developing intelligent computer-aided instruction (ICAI) – then it is a measure of how distorted our perceptions of both AI and education have become. AI, the science of designing computers to do things which would be considered intelligent if done by people, has a very wide brief – the fact that AI can save an oil company millions of dollars by telling it where to drill does not necessarily imply that AI can similarly solve problems in other areas, such as education. And it is a rather uninspiring philosophy of education which sees it as just another industry, whose prime aim is to serve the rest of industry.

The chapters in this book give better reasons for considering ICAI interesting and important. The authors were asked not to write detailed technical reports of their latest research but to put their work in a wider context (so that readers may better understand the aims and achievements of ICAI), and also to discuss problems – encountered or foreseen, solved or unsolved – and to speculate on future developments (so that readers may better judge the longer term importance of ICAI).

The result is a collection of papers which gives a considerable insight into what motivates people to work in this increasingly vibrant field. On the whole, it is not the prospect of improving educational efficiency – it is the prospect that ICAI will be an area where they may refine their ideas about important issues which interest them regardless of ICAI. Issues such as: What is the nature of knowledge? How can an individual student be helped to learn? What precisely is 'learning'? What styles of teaching interactions are effective when? ICAI is important to education because it may help to develop answers to these general questions.

Like all new fields, ICAI is both derivative and innovative. On the one hand, ICAI researchers bring with them or adopt theories and methodologies from associated disciplines such as psychology and computer science. This interdisciplinarity is, as usual, a strength and a problem, and it is reflected in this book where we have different, sometimes conflicting, perspectives on the same issue.

On the other hand, ICAI is innovative in that, as mentioned above, it contributes ideas back to associated disciplines and also – as it must if it is to justify its own label – generates research questions of its own. Many of these questions are discussed in this book. But there is no need to delimit precisely the field of ICAI (indeed, some of the authors in this book would not consider themselves to be working in ICAI at all!). We can be content with a broad definition, for example that 'ICAI is concerned with developing computer systems which interact knowledgeably with learners'.

This book, then, is intended to give a general introduction to ICAI. It is hoped that all the chapters will be accessible to the non-specialist, at least sufficiently so to allow the issues and objectives to be appreciated. The book should therefore be of interest to a wide spectrum of readers, including

- Researchers in artificial intelligence, human–computer interaction, cognitive science and education.
- Computer scientists,
- Information technologists,
- Psychologists,
- Educationalists,
- Teachers, and
- Anyone else concerned with educational innovation.

INTRODUCTION: A BRIEF GUIDE TO THE CONTENTS

The 24 chapters have been grouped into three parts: papers in Part 1 are mainly concerned with theoretical issues common to all ICAI systems; those in Part 2 are mainly concerned with techniques appropriate for certain components of ICAI systems; and those in Part 3 are mainly concerned with the application of ICAI to particular subjects.

The first chapter, by Beverly Woolf, sets the scene by presenting the ICAI enthusiast's 'standard line' on the potential of ICAI. She describes some state-of-the-art ICAI systems and discusses the benefits they provide. But she also emphasizes the fact that fundamental research remains to be done, particularly in the area of knowledge representation. The field of AI has made progress recently by recognizing the central role of knowledge representation, and it is clearly particularly important for ICAI systems, which might alternatively be described as knowledge communication systems. Indeed, ICAI differs from CAI primarily in its focus on the representation of knowledge of the subject matter and of pedagogical knowledge.

Jim Ridgway, in Chapter 2, presents a sceptic's view of ICAI. Readers will, I am sure, be able to form their own judgements about the force of his strictures after reading the other chapters. The only point I would raise here is that his perspective is from school-based mathematical education. We must be careful to distinguish between 'the classroom' as a generic term for a place of learning and as a term for the physical arrangement in present schools and colleges. ICAI researchers have no commitment to the latter. Other learning environments are conceivable and maybe even preferable. At this moment, the European Economic Commission is considering proposals to develop by the year 2000 studios and workstations to permit European learners to learn what, when and how they wish. ICAI will be indispensable for the fulfillment of such a proposal. In general, however, ICAI researchers – regrettably, perhaps – are more interested in the computational expression of principles of learning and teaching than in the provision of systems for real use in present educational settings.

Perhaps the main distinctive contribution that ICAI makes is in the area of student modelling. Within computer science, ICAI was the first area to take seriously the notion that successful human–computer interaction requires that the computer have some understanding of the human. The development of 'user models' is now an active research topic throughout interactive system design. It is particularly important in ICAI because it is the one class of interactive system whose express purpose is to change the cognitive state of the user, and we therefore need a dynamic representation of the user's current state of knowledge in order to determine how it may be modified. Within psychology, the student modelling effort can be seen as part of a trend emphasizing the individualistic nature of cognition rather than general cognitive processes. And within education, student models help clarify how we might provide the individualized instruction advocated by some educational philosophers.

William Clancey reviews the role of qualitative models in Chapter 3. As in AI generally, ICAI prefers 'qualitative' models, in which objects, processes and the relations between them are described symbolically or structurally, to 'quantitative' models, which might use numeric or physical analogues. Although, as Clancey remarks, student modelling is, unlike most other parts of AI, 'unabashedly psychological', it has in practice been driven mainly by computational theories of knowledge representation. In Chapter 4, Stephen Payne attempts to redress the balance by relating student models to theories of cognitive skill acquisition and particularly to recent ideas about 'mental models', which share the emphasis on individualized theories.

In Chapter 5, the most technically demanding chapter in the book, Stefano Cerri picks up the knowledge representation theme raised by Beverly Woolf. He argues that all cooperative dialogue systems, including ICAI systems, would benefit from new computational paradigms for knowledge representation languages, demanding the resolution of certain philosophical and psychological questions concerning the nature of knowledge itself.

The last two chapters of Part 1 address different aspects of the question of how we evaluate ICAI systems. Evaluation may be attempted at a global level, that is, in terms of whether the complete system meets specified objectives – as discussed by Lindsey Ford in Chapter 6. Or it may be attempted at a 'local' level since often the ICAI system designer's real interest lies not in building a complete system but in developing a micro-theory serving as one component of such a system. As Tony Priest and Richard Young explain in Chapter 7, traditional methods are not satisfactory for evaluating the kinds of theories used to build student models. They propose two new methods and discuss their properties.

The chapters in Part 2 discuss particular techniques and ideas for components of ICAI systems. The first two chapters develop proposals for student models. Gerhard Weber, Gerd Waloszek and Karl Wender argue in Chapter 8 that knowledge is mainly case-based and hence that student models should be more episodic in nature. This, they believe, would better enable ICAI systems to provide individualized remindings and analogues to promote learning.

One of the functions of a student model is to help diagnose misconceptions – indeed, there is little point in maintaining a student model if the student learns as predicted or hoped. Two approaches to diagnosing misconceptions (discussed in other chapters) are to build extensive subject-dependent libraries of misconceptions ('bug libraries') and to use machine learning techniques to generate the misconceptions. In Chapter 9, Ernesto Costa, Sylvia Duchènoy and Yves Kodratoff describe another method, that of inferring a student's misconception using the formal technique of resolution from computational logic.

The next three chapters all combine an acceptance of the fact that accurate student modelling is a practical impossibility with a proposal that ICAI systems should adopt a less rigid tutorial style than is usual in order to foster more exploratory learning. In Chapter 10, Mark Elsom-Cook discusses the use of 'bounded user models', which essentially provide bounds for student models, to support a range of teaching styles. The maintenance of dynamic computer-based student models is necessarily a problem of machine learning, an area of AI research which its practitioners claim has progressed significantly in the last decade. However, David Gilmore and John Self conclude in Chapter 11 that machine learning techniques are not yet adequate for direct incorporation in intelligent tutoring systems but that they may be able to support a collaborative style of interaction. Rosemary Todd in Chapter 12 echoes the rejection of expert-system-based ICAI expressed in the preceding two chapters and elsewhere in the book – it being a standard misconception outside the field that ICAI systems are, by definition, implemented by enclosing an expert system (a program capable of high performance in some specialized domain of expertise) within a tutorial package. Her approach makes use of the principles of self-organized learning to support individualized learning.

An ICAI system should endeavour to interpret the student's inputs to the system not merely in terms of items of knowledge understood or not but as evidence about the student's goals, i.e. what he is trying to achieve. This, of course, is more important as we move from directive to open styles of interaction, as advocated by many authors in this book. The problem is closely related to a well-established body of AI research, that on planning and specifically on plan recognition. Chapter 13 by Mark Woodroffe and Chapter 14 by John Jones, Mark Millington and Peter Ross both address the problem of understanding a user's goal-directed behaviour when using a computer system, coincidentally the same system, the file commands of the UNIX operating system.

The last chapter of Part 2, by Rod Nicolson, applies AI techniques not to the implementation of ICAI systems but to the development of an authoring system to aid the implementation of (conventional) educational software.

The nine chapters of Part 3 are concerned mainly with applications of ICAI to particular subjects. One of the trends in ICAI in recent years has been to move away from subjects in traditional curricula towards intrinsically computer-based subjects. There are several reasons for this. Firstly, the implementation of any ICAI system demands considerable subject knowledge and it is more convenient for designers to have ready access to this knowledge, which tends to mean that it is knowledge of some aspect of computing. Secondly, designers of ICAI systems for standard school subjects have to argue their benefits over existing methods, an argument which is often of no direct interest – the argument scarcely arises with ICAI systems for computer-based subjects such as programming since there are no non-computer-based existing methods. Thirdly, there are few philosophical objections to the appropriateness of ICAI for computer-based subjects, it being seen as just part of a general desire to provide user-friendly, learnable software systems. In any case, the present somewhat incestuous emphasis in ICAI is perhaps a temporary matter, for much of what students need to learn will become increasingly computer-based and so susceptible to the ICAI approaches being developed.

The chapters of Part 3 fall into three groups. The first group applies ICAI to 'traditional' subjects, specifically, arithmetic, writing and basic physics. The three chapters share an emphasis on trying to elucidate the nature of conceptual understanding and misunderstanding within their respective domains, rather than 'merely' building a system to support subject learning. In Chapter 16, Tim O'Shea, Sara Hennessy, Rick Evertsz, Ann Floyd, Mike Fox and Mark Elsom-Cook describe a project to build an arithmetic tutor which replaces the focus on drill and practice with an attempt to provide tools to promote mathematical thinking. In Chapter 17 Mike Sharples and Claire O'Malley develop a framework for a computer-based writer's assistant. This chapter illustrates how the nature of skills may be radically altered by the provision of computational tools and how we need to re-think how those skills may be learned. Michel Caillot in Chapter 18 describes the design of a tutor for basic electricity, concentrating on the role of prototypical knowledge.

The next group of three chapters illustrates the use of ICAI techniques to make computer systems more learnable and usable. All are concerned with the design of interfaces for electronic mail systems, although the principles are, of course, intended to be more general. In Chapter 19 Martin Cooper describes the design of a self-adaptive interface, mainly from an MMI (man–machine interface) perspective. The next two chapters consider intelligent help systems, that is, systems which support the user while he is trying to perform some computer-based task. Joost Breuker, in Chapter 20, describes the implementation of teaching and coaching strategies initiated by the help system while monitoring and interpreting the performance of the user. In Chapter 21, Roger Hartley and Michael Smith describe the 'user-initiated' component of the same help system, that is, the part which provides appropriate explanations in response to user questions.

The design of systems to help students learn computer programming is the subject of the final group of chapters. Here, ICAI merges with more standard computer science, such as compiler design, software engineering and formal specifications of programs. Mark Elsom-Cook and Benedict du Boulay describe in Chapter 22 the use of chart-parsing techniques to check the syntax of Pascal programs, to provide more appropriate and more informative error messages for beginning programmers. Lewis Johnson's system (Chapter 23) is more concerned with interpreting syntactic and semantic errors in terms of the programmer's intentions, i.e. what the programmer is trying to achieve. This requires that the system have some means of describing 'intentions' and it is interesting to see that this project is merging with more formal approaches to defining program specifications. The final chapter, by Jeffrey Bonar and Robert Cunningham, is not concerned with an after-the-event analysis of complete programs but with supporting the novice programmer on-line through all stages of the programming process. They describe the use of modern workstations to help students define and manipulate intermediate representations such as programming plans.

The book ends with a cumulative bibliography for ease of reference. Please note that where the pronouns he or she occur in the text, referring for example to the student or the teacher, they should be taken to mean either sex.

ACKNOWLEDGEMENTS

On behalf of all the participants, the editor would like to thank the American Association for Artificial Intelligence and the UK's Science and Engineering Research Council for supporting the Workshop from which these chapters are derived. I am deeply grateful to the chapter authors for so enthusiastically providing readers with this informative introduction to the important field of ICAI.

John Self *November 1986*
Lancaster

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