Anti-Hodmanship: A Report on the State and Prospects of CAI

Gordon Pask

Dear Editors,

In reply to your inquiry, the art of computer-assisted instruction (henceforward CAI) is in a pretty dowdy state; a sort of depression. But the condition is improving quite rapidly and the recovery should be complete. Perhaps I can say this without seeming to be unduly critical just because I know of no one older in this (fortunately youthful) field, thus combining the advantage of a historical perspective with the culpability of a participant. At any rate these remarks, though occasionally acid, are intended constructively; neither as indicators of derogation nor exasperation.

1. The maladies are as follows:

(1) Research in this area has been chronically underfinanced in Europe and (less obviously so) in the U.S.A. and the U.S.S.R. Moreover, a rather large proportion of the money allocated to research/development has been mis-spent on respectable looking but pedestrian head counting and mark counting projects, or studies in which one juggernaut of a system is compared with another (on grounds that cannot, in the nature of the problem, be fully specified). These symptoms are nowadays less obtrusive; on the one hand, because of a growing realisation that CAI is important and that it is a " hard " science: on the other, because many of us have learned the salutary lesson that it is better to say what you want your system to do before investing in the machinery to do (or not do) it.

(2) Over the last 15 years, the CAI sub-culture has been obsessed with cost effectiveness criteria which, though reasonable in themselves, are consistently misinterpreted (just how, we shall see later). Since there is an internal misperception about the scope of CAI and thus the benefits likely to accrue from its implementation it is not surprising that the cases made to administrators have been, and to some extent still are, improperly stated, so that the standards of effectiveness are commonly inappropriate. For example, it is rarely meaningful to make estimates in terms of student hours or " station " hours or stored " words " per student hour. More subtle indices are needed and are nowadays available.

(3) Pragmatism is a good idea; take it for granted. But there are two species of pragmatist, at least. One interprets pragmatism as the valuable but prosaic solution of problems formulated on the basis of conventional wisdom. His occupational hazard is to mistake the regurgitation of solution methods for problem solving. The other type of pragmatist is an inventor. The trouble with him is that he poses more problems than he solves. Both kinds have their place in things, and they operate at all levels (theoretical, scientific, and technical). But, in a developing field like CAI, the innovative pragmatist is essential. Unfortunately, his activities have been discouraged in (rightly) demanding a pragmatic approach so that the first type of pragmatist came to dominate the experimental field; to the extent of being accepted as the *only type* of pragmatist.

One symptom of this bias is that our sub-culture used to suffer from the time-consuming pursuit of technical detail; for instance, studies of frankly outmoded terminals; trying to make sensible systems work in unsuitable computer-oriented languages or user-oriented languages (like the earlier members of the *Coursewriter* series) built for the realisation of programmed instruction alone. Somehow these pursuits were conceived as worthy; nowadays, they are generally agreed to be fatuous as well.

(4) Another fairly ubiquitous activity, also deemed worthy, was the habit of smudging empirical data about learning with various statistics. In the condensed records that emerge from this process, any information that may have been obtainable about learning as an explanatory, strategic, creative, or idiosyncratic process is obfuscated. Naturally, the data are well suited to the " respectable looking " studies, criticised in (2) above, but they have little bearing on education, either in theory or in practice.

(5) For a period, the sub-cultures of CAI and " Artificial Intelligence," so clearly companions in cognitive psychology and applied epistemology, were separated. Gladly, their estrangement has ended in reunion rather than divorce.

The change in thinking came about for several reasons, but one of them was the resolution of a prevailing confusion between computation science (cybernetics, system theory or just computation unqualified) and the operation of existing computing machines. It is true that computation science often uses computers as tools. But its subject-matter is much broader. Computation science deals with relational networks and processes that may represent concepts; with the structure of knowledge and the activity of real and artificial minds. Computation science lies in (even *is*) the kernel of CAI; it lends stature to the subject and bridges the interdisciplinary gap, between philosophy, education, psychology and the mathematical theory of organisations. Computer techniques, in contrast, bear the same relation to CAI as instrument making to physics or reagent manufacture to chemistry.

These facts, above all others perhaps, have changed the rather gloomy picture painted in (1), (2), (3) and (4).

In the context of a unified science of education, many aspects of which call for computer assistance if they are to be practicably realised, it is possible to resolve the dilemmas of (1) and (2); to say what we are really up to and to make an honest case to our patrons and sponsors. It is usually possible, in this context, to " say what the system should do " (often after some highly sophisticated and mechanised but small-scale experimentation) and thus avoid an embarrassing clutter of smart but misbegotten facilities. Likewise (3) becomes outmoded as a criticism, along with the terminals. Though there is a legacy of unsuitable hardware and software it is realised that fiddling with its quirks is " making the best of existing equipment," and not a serious pursuit in its own right. Finally, the condensed results of (4) (not, please, the data which may be excellent), stand out as the irrelevant piffle they are.

2. That is the present *state* of the art. Let us turn to the aims of CAI and the body of knowledge on which its growth as an art or a science or a technology is founded.

Here, the viewpoint will be idiosyncratic; some people share it, others have different ideals and divergent, though equally defensible, intentions.

(1) Most people in the educational profession (teachers, psychologists, university professors, curriculum designers, ETV producers, graduate students, and CAI merchants) have a sense of vocation. If you do not have, you will find it hard to make sense of the remaining paragraphs. Many of these practitioners owe their vocations to having at least glimpsed some moment of excellence; the power of evolving symbolism, the sheer joy of comprehension. The phenomena in question are varied. A child suddenly learns to learn, and you account for it by some sort of

neurophysiological change; but you know that the explanation is phoney and really you saw a miracle. A culture is engendered by a project; sometimes by an idea; or an adult who seems to have died in his twenties comes alive again. A design class in California, where the students were ignorant of electronics, gets, uses and innovates with, laser technology; all in a week. Von Foerster has over 100 well-documented examples, Illich more than 1,000, Papert has legions of instances, my own students have many. I know full well that a new renaissance is going on around us and see the signs of it as much in the ikons and the rituals as in the Ph.D. theses.

Though diverse, these phenomena are all evolutionary rather than revolutionary (a half-truth; they are non-destructive). They are all dramatic, large in magnitude and unmistakeable. They are all inexplicable within the standard scientific framework attuned to rationalising more picayune events (that is, a framework more or less copied from macrophysics, where it is apposite, to psychology, where it is not). Hence, we are trained not to notice them; but do so, and marvel.

Because there *are* such moments of excellence it is not absurd to escape from the fashionable pessimism spawned by " world dynamics " and other simple-minded forecasting schemes and feel a vocation to do something (but what?) about it all.

In general life, the phenomena dubbed " moments of excellence " are rare; a circumstance that is only in part attributable to the dissonance established by conventional training in scientific *techniques*. The chief reason for their rarity can be uncovered and represented formally; I shall gloss a lengthy argument by saying the world of learning and knowledge does not contain enough situations that count in a valid, non-trivial, very profound sense[1] as *conversations*; for there, and only there, are such moments of excellence manifest. On that account the new renaissance is a local phenomenon; symbolic evolution does not take off. It is not simply that moments of excellence are infrequently observed but also that, except under special and propitious conditions, neither are they evident to the participants.

How could moments of excellence be made more frequent (and, I wager on good grounds, more excellent)? There are several methods. The danger with most of them (Essalyn, the group techniques, the magician) is that the conversations induced with their assistance degenerate into the exercise of empathy as a surrogate for intellect. The perfectly predictable reason for this pathology is that the discourse is not effectively coupled to the growth of knowledge and is apt to be dissociated from cultural (and familial) tradition, hence the need for an order in which moments of excellence become immutable is half satisfied by rituals born of the limbic system, not of civilisation. As catalysts of conversation, immune to these defects, we have left the priest, the guru, the theatre and (odd though it may sound) the human use of CAI.

That, I think, is CAI's important role; to foster conversation which is coupled to a corpus of wisdom (some of it encoded no doubt, but some of it not) and thus to increase the frequency with which moments of excellence occur. The other legitimate agents (priests and dramatists) may use it in conjunction with educators, as a major tool; an amplifier and, quite possibly, a spur to innovation in its own right.

---

[1]Please pardon the emphasis; but I am not (whatever else) talking about the so-called " conversational " interaction between a man and an on-line computing machine. The word is used in all earnestness with its full meaning. On the other hand conversations need not be strictly interpersonal and certain man-machine interactions (of a not very well publicised type and mostly using visual rather than verbal utterances) also count. I am quite prepared to justify this at first sight outrageous claim to any interested reader.

Why should that be so important? Well, just because education is all about learning to learn, or teaching to learn or learning to teach, to create, to evolve. Apart from the alphabets (of letters and numerals), some notions of right and left, perhaps a bit of the multiplication table, facts can be stored in an engine that fits in your pocket. It is a waste of that most precious commodity, time, to store them in your brain. Moreover, a plethora of facts permanently inscribed in the brain may impede those mental reconstructions, explanations and explorations of concepts that constitute *memory* (parenthetically *memory* is not at all the same as storage, *that* at least becomes obvious on turning from *computer operation* to *computation science*).

Moreover, the following statements are true. Education is a regulatory system of civilisation. The current dimensions of communication, transportation and government render *it* the primary regulator. Even if society is decentralised, as the more thoughtful ecologists recommend, an educational system between five and 1,000 times more efficient than any one commonly and currently available is needed to avert, quite literally, collapse. That need is recognised in countries (like Mexico) with a high growth rate and a conventional school system that cannot possibly expand fast enough; there, they are using unconventional means to solve a pressing problem. But any means able to give the requisite magnitude of enhancement must, I submit, make each lesson into a focus of those currently rare " moments of excellence." If I did not believe that CAI could do that (it is a belief, though a reasonably founded one) I should not be in the field.

If you subscribe to this dogma then the criticism of section 1 (2) is stripped of its superficial perversity. Current evaluation schemes are based on the idea that CAI is " no worse than " other methods; here it must be vastly better to merit consideration at all. Also the criticism of section 1 (3) is far from capricious; the criteria being condemned are precisely those that level excellence into a higher mediocrity and obscure the exercise of individual strategies for learning or teaching which, in this context, prove all-important determinants of efficacity.

(2) It will be obvious that CAI, viewed in this light, does not resemble an elaborate branching program; nor is it necessarily concerned with operating booths and student stations.

Further, it is clear that some major revisions of thinking, very fundamental ones, must underlie the contention if it is to be taken seriously, as I hope it will be. CAI itself is the handmaiden of these innovations, but also, in a curious way, the progenitor of some of them.

In the remaining paragraphs I shall do my best to sketch (in most cases from their historical origins) the developments that culminated in a complete revision of thinking about such matters as learning and teaching; also to outline the features of those CAI systems able to sustain tutorial conversation and thus to magnify the force and scope of the educational process.

In the interests of brevity, these comments are slanted towards work in my own laboratory and few specific references are given. I appreciate, of course, that other people have worked concurrently along the same lines; their work is not stated explicitly. The reader anxious to remedy this imbalance (whilst retaining essentially the same stance) is referred to papers (listed at the end of this article) in which I have reviewed the subject giving proper and necessarily lengthy acknowledgements to other workers in this field. The volumes in which these papers appear cover CAI quite comprehensively and often from different points of view.[2]

---

[2]Good abstract services that concentrate on CAI are provided by the following agencies—Entelek; OECD; Training Research Abstracts; Enfield College of Technology; School of Education, Mälmo, Sweden; Dept. of Commerce Washington (Translated Reviews of U.S.S.R.) and Council of Europe, Strasbourg, Survey Project 1970.

(3) Many operations are performed by a real life CAI system. For example, it may act like a library access device to retrieve data or instructions from a storage bank. It may record and aggregate a student's performance; it may construct gradings for a class, and so on. Though often of great importance, these features are peripheral to its main and minimal function: to interact with the student(s) and either to *teach* or else to *guide* a learning process. Concentrating on this function (for the other features can usually be added as required) let us start with the first instance of a teaching operation that called for computation on the part of a *machine*.[3]

During the late 1950s a number of adaptive teaching systems, mostly using special purpose computers, were employed for instructing both intellectual and perceptual motor skills; some of them being commercially exploited. These devices increase problem difficulty to compensate for a student's increasing proficiency (which they continually sense) and, vice versa, reduce it, if a student runs into trouble. Unlike the simple feedback arrangements embodied in a programmed text, or the slightly more sophisticated feedback tricks of a branching program, these CAI systems adjust and aim to optimise the criteria which govern adaptation. Moreover, they are generally multidimensional in so far as they compensate differentially for distinct response components and/or error factors. By about 1964, when similar arrangements were embodied in computer programs, it was clear that learning can be controlled and, in a limited sense, optimised by these devices, if, and only if, certain conditions are satisfied.

(a) There must be an adequate model for how the student solves problems and engages in the higher level problem-solving which is one facet of learning; otherwise there are no grounds for rating problems as more or less difficult (a cue, for example, may actually be misleading). (b) There must be a model for the subject-matter. (c) There must be a class of justifiable teaching strategies (together with means for measuring and predicting proficiency). (d) The man-machine interaction must be rich enough to sustain a dialogue.

For some situations, these requirements are satisfied and, if so, the man-machine interaction resembles a rather restricted conversation; it is, for example, entrapping. If not, the system's behaviour is manifestly instable. But, even when the conditions are not satisfied, it is still useful to regard all modes of adaptation as regulators of a student's uncertainty and to note that uncertainty regulation, by one means or another, is a prerequisite for effectual learning.

Except in the latter form, the adaptive paradigm fails to encompass realistically large learning situations, though it has a local utility attested by a great deal of experimental data, some of it quite recently garnered. Nevertheless the problem areas delineated by (a), (b), (c), (d), still provide a framework, which is used in section 2 (5) for discussing present-day issues.

(4) Around this period five separable lines of development got under way, using various subject-matters and categories of student:

(A) Production of systems for general tutorial conversation that could adumbrate topics of educational interest and a theory to go with them.

(B) Implementation of learning groups, in which students teach one another under the surveillance and guidance of a monitoring machine.

---

[3]After all, the adult participant in one of Vygotsky's " paired learning " experiments, computes the child's expected mode of behaviour; the author of a " structural communication " text or a mathetics text computes also, though he relegates on-line condition testing to the student himself.

(C) Scrutiny of the ways that a computer can be used in teaching. For example, it may be employed directly (as in section 2 (3) but usually augmented by an inquiry facility). Or, it may be used as a simulation tool, for instance, to present a country's economy in the form of a dynamic microcosm. Again, it can be used as a laboratory (*e.g.* in mathematics) with or without the pattern recognition capability to discern *what* or *how* the student makes laboratory models.

(D) Design of hardware and software systems, some of them (like PLATO or IMPACT) very elegant ones, for interfacing the tutorial.

(E) Development of means for accessing student terminals and/or data storage which are economically feasible for large student number and/or storage capacity (for example, ALF, which though rather inflexible as a student facility, has impressive characteristics in this respect).

Of these developments, very little will be said about (D) or (E). Item (B) can be treated alongside (A) and (C). The teach-yourself idea is powerful and the notion of a " learning group " is quite distinct from the notion of " many students treated individually by a single processor " (a more familiar plan). But it is approximately true to say that any conversational system can be extended, in principle, to deal with an n-person conversation where $n > 2$. The practical difficulties involved in instrumenting the scheme are likely to decrease as concurrently operating processors come into vogue as they are beginning to do.

(5) To take up the theme of section 2 (3). Item (a): a system that adequately models a student must be able to *learn* in a non-trivial sense, not merely to *adapt*.

First, the CAI system must learn because there are salient individual differences between students and changes in problem solving method that occur in the course of learning. Fortunately, students fall into theoretically predictable (and empirically verified) categories on a given occasion, *i.e.* any student who is free to do so adopts one *class* of learning strategy in respect of a certain subject-matter; moreover, there is a general individual *disposition* to adopt one or other class at the outset. Very crudely, there are students who have no overall concept of the subject-matter and must be instructed in order to learn (these can be eliminated from the population by using a special pretraining technique that shows them how to learn, *i.e.* to acquire a " learning set.") Of the remainder, some students prefer to move one step at a time and typically to isolate a topic about which they become *certain* before proceeding. Other students prefer to tackle the matter holistically; to access many topics in pursuit of their goal and, typically, to show confidence about solving problems under this goal long before they are certain of what to do.

Next, the CAI system must learn in order to interact with the student in his own terms. There is a current dispute about how much liberty a student should be allowed and the amalgamated result indicates " not too much, but not too much restriction either." The fact is that *if* a student is given liberty to explore, he (any pretrained student, or anyone with the requisite foresight and self-awareness to begin with) *can* learn fast. But *if* he is given liberty, then the CAI system must match its strategy to his style and it can only do this if *its* data structure images *his* concept of the material.

All of this depends upon a model for the subject-matter (item (b) of section 2 (3)). Simple hierarchical schemes in which topics are treated like nouns *do* work to *some* extent (so-called knowledge structures) but a much more complicated picture of the subject-matter is mandatory for serious work. In it, topic names are treated like verbs and the entire mesh is cyclic in form.

Its canonical representation, as a graph, is called an entailment structure, and represents what *may be known.* It is crucial that the entailment structure depicts many permissible and possible ways of getting to know the subject-matter and, for each topic, at least one way of reconstructing the requisite concept from the concepts required to deal with topic relations that are already understood.

Although an entailment structure is not generally learned *by* the CAI system (*i.e.* it is prepared by subject-matter experts and analysts beforehand), it must be available to the system in order to accommodate the " learning about the student " already deemed mandatory. For example, the distinction between strategic types can only be exhibited in respect of an entailment structure for the subject-matter (on which any strategy appears as a certain cluster of *markings*); any message or advice delivered to the student on the basis of knowledge about his strategic type and competence is also contingent upon the entailment structure.

The teaching strategies (item (c) of section 2 (3)) come into the same domain as the learning strategies which would be generated by a self-aware (if need be, a pretrained) student in the absence of tuition. Many variants are possible, of course. But it can be shown that at least one condition is essential, *i.e.* any teaching strategy employed to enforce or to guide learning must be matched to a learning strategy (I) that this individual is prone to adopt and (II) that he is competent to execute if left on his own.

Regarding item (d) of section 2 (3) it is generally recognised that the man-machine interaction language should have many of the capabilities of natural language. There are numerous technical difficulties in the way of programming computers to interpret and manipulate full natural language dialogue. But it is important to see the wood for the trees. Roughly, the essential features of an acceptable language are that it should accommodate (α), asking questions that call for explanations in reply and which may legitimately treat many forms of explanation as correct (in contrast, most current languages, though they seem to be more powerful, are only able to comprehend multiple-choice or list questions and to adjudicate an answer or a list of answers as correct or not); (β) the language should be capable of representing analogy or, in literary terms, metaphor (either loose or structured).

It is hard to satisfy these requirements in the context of typed or spoken utterances and the current difficulties seem to present an insuperable barrier. But, to some extent, the problem is spurious. Using a visual display modality, and the modelling facilities mooted in section 2 (4) (C), it is possible to elicit modelling or constructive operations that are, within the terms of reference, one (or sometimes many) modes of explanation; further these can be " pattern recognised " and judged as satisfactory or not with respect to the entailment structure for the subject-matter.[4] By the same token, such models *can* be interpreted as expressing analogies (though not, as yet, verbal metaphors).

The point is important because it turns out that though responses to multiple-choice or list questions furnish valuable indices of a student's uncertainty and/or belief, they give little information about whether or not he possesses a concept and (more important) is able to reproduce it or reconstruct it as a memory. On the other hand, replies of an explanatory type do provide this information. Under appropriate circumstances a student can be said to *understand* a concept if he is able to explain it and to explain how he achieved it. One way of putting this point is to say that he could teach the concept to another student. If the necessary facilities

[4]Strictly, with respect to a *task structure* or *command graph* one of which is linked to each node representing a topic in the entailment structure.

are made available for this purpose then they can be employed, also, for the *laboratory* use of the computer; as a playground in which the student can construct and innovate.

Amongst the possible teaching strategies (section 2 (3) (c)) that have been mooted there is at least one class that shows the following properties and these strategies (by their nature) permit the student a constrained degree of liberty. These, rather than the adaptive paradigm (section 2 (3)), are now dubbed conversational.

(6) (i) As a pre-requisite for executing these strategies, the CAI system must furnish the student with a copy of the entailment structure for the subject-matter: we use a large map-like display. The points representing separate topics must be accessible and must be marked to indicate, at any instant, the topics the student is exploring; that he appreciates or is aiming to learn; the topics (usually several) he is currently working on; and the topics he already understands.

(ii) Any exploration strategy (a plan for learning whatever the entailment structure permits) is selected as a compromise between the student's option and the machine's (biased according to the desired mode) but so that the student's preferred learning strategy is matched (Condition (I) and Condition (II) of section 2 (5)); and so that the student shows evidence that he *can* learn in the prescribed fashion.

(iii) Matching secures a situation in which the student's gross level of uncertainty is regulated, but

(iv) Local conditions are adjusted (by a modified adaptive routine) so that his uncertainty in respect of the currently aimed-for topic and the cluster of currently worked-on topics is held within limits.

(v) Once committed to a topic, the student must explain it. Some CAI systems are able to interpret symbol string explanations; we use and prefer an explanation that is physically modelled by the student on a laboratory facility, inspected by the machine. A topic is marked *understood*, if and only if the student can both explain it and show how he learns to explain it.

(7) These are not the only teaching strategies, of course, but they are, in practice, remarkably effective; yielding an enhancement of learning between two and more than ten times the standard value (depending upon whether free study or rigidly controlled instruction is taken as the basis for comparison). There is appreciable transfer of " learning to learn " and good retention. The data obtainable from such a system give a detailed picture of progress, are more revealing than a gross learning and retention score and have obvious diagnostic value. The price paid for all this is quite large. In addition to tutorial text and graphics it is necessary to display a dynamically marked representation of the entailment structure and to construct a task specific simulator for modelling and eliciting explanations. On the other side of the coin, these facilities can be designed (and have been built) for subject-matters as diverse as statistics, applied science and history.

My own, experimentally deployed, equipment for executing conversational strategies (or any degenerate variants) has the acronym CASTE (Course Assembly System and Tutorial Environment). But we know that CASTE can be replicated on four student stations' worth of PLATO and hope to realise a transcription onto some such large-scale CAI facility in the near future.

(8) You may regard section 2 (1) as a euphoric vision; an obverse to the earlier deprecated depression. Or you may regard it (as I do) like the image on a jigsaw puzzle box, awaiting the pieces to make the picture real.

The pieces needed to reify moments of excellence are given, in part, by actualising a tutorial conversation. But if they are to form a coherent pattern they must also have formal status both as psychological and computational units. It is at this level that CAI becomes an enthralling science. CASTE for example, was built in well-informed faith. It worked (hence, it is a pragmatically justifiable tool) and it furnished empirical data. But *subsequent* analysis of its operation has revealed that it only *can* work if the following statements are true: each one (it is a partial list only) tags one of the integrable units required to make sense of section 2 (1) at its face value and is also needed to justify some apparently sloppy arguments (especially for example, the cavalier approach to n-person conversations in section 2 (4)).

(a) A knowable topic is a relation.

(b) A *concept* is the reconstruction (technically, the reproduction) of a topic.

(c) A *memory* is the reproduction of a concept.

(d) An *individual* is a class of self-reproducing memories, viable in the surroundings afforded by suitably (and definably) related topics. Some sociologists would call it a *role*.

So, as characterised in a tutorial conversation, an individual may be correlated with one man, one brain; or it may be immanent in a group of men; or it may be that there are several in a single brain (as, when you " learn alone " you really house a distinguishable " teacher " and " learner "; both individuals).

From this point, we can assemble a theory of education which is somewhat beyond the scope of this article, though it is extremely relevant to the development of CAI. Instead, I shall conclude with one remark, emerging from this theory, which bears on all manner of CAI systems and provides a canon for appraising them. If a system is legitimately said to *teach*, then it must be able to *learn from* its *student* who may reverse the roles to play at *teacher*. That is what tutorial conversation *means*; I submit it is what *teaching* (in contrast to indoctrination, instruction, or ill-disciplined cavorting with knowledge) really means.

There is one interesting corollary. Whatever may be learned (the entity called an entailment structure in section 2 (5)) is fixed only for convenience. In general, it is open to growth and that is both theoretically the case and factually so (the course assembly aspect of CASTE which has not been discussed). In a very formal sense, there are gaps in knowledge and (as a conjecture) there are some unknowables; but to learning there is no end at all.

Acknowledgement

The research reported in this document has been supported (under various contracts and grants) by the Social Science Research Council of Great Britain or the U.S.A.F. Office of Aerospace Research through its European Office and carried out at System Research Ltd.

I wish to thank Mr. D. Kallikourdis and Mr. B. C. E. Scott for reading through and commenting on this paper.

References

Pask, G. and Scott, B. C. E. (1972) " Uncertainty Regulation in Learning Applied to Procedures for teaching concepts of Probability," Final Scientific Report SSRC Research Grant

HR 1203/1, System Research Ltd., January 1972. To be published in *International Journal of Man-Machine Studies.*

Pask, G. and Scott, B. C. E. (1971) " Learning Strategies and Individual Competence," SSRC Final Scientific Report HR 983/1, System Research Ltd., January 1971. To be published in *International Journal of Man-Machine Studies.*

Pask, G. (1970) " Fundamental Aspects of Educational Technology, illustrated by the principles of Conversational Systems," in *Proceedings IFIP World Conference on Computer Education*, Vol. 1. *Invited papers*, R. Sheepmaker (Ed.). pp. 1–29 to 1–52. Amsterdam: IFIP.

Pask, G. (1970) " Computer Assisted Learning and Teaching," in *Proceedings of the Leeds Seminar on Computer Based Learning.* J. Annett and J. Duke (eds.) pp. 50–63, NCET.

Pask, G. (1972) " The Automization of Instruction and the Nature of Learning," in *Proc. Lehersysteme* 72 *Berlin*, P. Weltner (ed.). Munich Ehlehwirph Verlag, Revised version to be published in *International Journal of Man-Machine Studies.*

Gordon Pask is Director of Research at System Research Ltd., he is also Professor in the Department of Cybernetics at Brunel University and Professor in the Institute of Educational Technology at the Open University.