SAVANT: How to Help Engineers to Learn New Concepts

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SUMMARY *The increasing demand for engineers in fast-changing specialities requires new ways of teaching technical subjects in higher engineering education; but introducing computers as ordinarly learning tools is far from being simple. For the past 10 years, we have been exploring original ways of using new technologies to help students learn new concepts. The solutions which were experimented with in Telecom Paris by engineering students include an hypertext encyclopaedia, a multimedia network system and an intelligent tutoring system which tries to sustain 'natural' conversations with students. All these systems were designed for the same specific purpose: to help the students learn new technical concepts by themselves.*

1. Specificity of the Telecom Paris Context

Telecom Paris is one of the engineering schools belonging to the French Telecom University, where high-level engineers are trained for a wide range of careers. Each of them may work in the electronics industry, communication networks, the software industry, etc. This explains why they spend most of the time learning concepts during their scholarship in Telecom Paris. This distinction between concepts and skills is a fundamental one, since all the systems described here were designed to help students learn new concepts. These technologies would be of little relevance in other types of context where the main objective is to ensure that students acquire new skills. The first system, SAVANT 1, was designed in 1981 in an attempt to reduce the difficulties encountered by students trying to understand a new idea.

2. SAVANT 1: An Hypertext Conceptual Encyclopaedia

As these students are familiar with learning by themselves, we tried to list all the problems that they might encounter and that prevent them to learn more rapidly when they are reading a textbook alone. We observed that the main difficulty lies in references to context or to prerequisites. We decided to design a conceptual information display system in which:

- context is suppressed;
- every reference to prerequisites is clearly highlighted.

These two simple principles have many consequences when the structure of the electronic encyclopaedia, which was designed for the students, was developed (see Fig,. 1). This encyclopaedia, named SAVANT 1, contained more than 3000 pages which could be accessed through 850 keywords. These pages were displayed on a minitel (French videotex terminal) that each student could use in her/his room.

Likelihood ratio

By definition: $$V(z)=\frac{p(z|H1)}{p(z|H2)}$$

In case of two *hypotheses*, V(z) measures the greater *likelihood* of the first *symbol emission* compared to the second symbol emission after the *observation* z.

$V(z)$:	likelihood ration of H1 to H2
$H1$:	hypothesis "observation of the first symbol"
z:	element of the observation space (of finite dimension)
$p(z\|H1)$:	conditional probability density

FIG. 1. Conceptual information display system for SAVANT 1.

Our choice to display context-free conceptual definitions required a complete reformulation of the definitions found in textbooks. A definition which was too long has to be split, not 'spatially' but hierarchically: sub-concepts had to be extracted, given a name and presented as every other concept. The same problem arose with theorem proofs. A proof which was too large had to be reorganized into a hierarchy, and presented through a window system. Opening a window allowed access to a more detailed level, and all the steps in a given level were displayed in a single window.

SAVANT 1 could be seen as a hypertext system, but it was more and less than this at the same time. It is a hypertext because a user could jump from one definition to another by definition, and then return to the original position. One feature of SAVANT 1 did not exist in usual hypertext systems. SAVANT 1 created a difference between local keywords which are only valid on the page where they appear, and general keywords which are defined everywhere in the encyclopaedia, and which do not have to be redefined each time they appear.

After several experiments a fundamental limitation to the user's possibilities had to be introduced: unlike other systems, the SAVANT 1 encyclopaedia cannot be read sequentially, to prevent users from browsing forward through unconnected concepts [1]. Random and sequential access modes were found to be strictly incompatible, using conceptual definitions. But this was not sufficient. It was disappointing to note that students did not use the encyclopaedia spontaneously. The mistake had been to believe that they would access the minitel when experiencing some difficulty in understanding a passage of their textbook. This was not actually the case. They consulted SAVANT 1 but not when a problematic situation arose.

We decided to add a separate sequential presentation of concepts which we called the narrative presentation. With both sequential and encyclopaedic reading modes, SAVANT 1 succeeded in becoming a normal learning tool for our students. A carefully studied student sample revealed that students used the system once a week on average (cf. [2]). A few of them used it daily.

Having thoroughly studied the structure of a context-free conceptual encyclopaedia, we carried out an investigation to find new ways of presenting conceptual information in a narrative way, since a narrative presentation had proved to be necessary. To take advantage of the capabilities of the system a non-linear presentation was offered. The underlying encyclopaedia already preserved the opportunity of having a non-deterministic route through a given course, but this was developed further by having the possibility of 'navigation'.

Consulting navigation is possible when items can be geometrically structured along several axes. The user is prompted to move in a continuous way in a multidimensional space by changing only one coordinate value each time. We designed a course on telematics which was organized along three axes: a temporal axis (past, present, future), a technical-level axis (service, organization and technical levels), and an axis representing the communication link (server, network, user). Students were invited to visit telematics as they would visit a town. They could take a walk through concept presentations, but could not jump from one concept to another (unless they used the underlying encyclopaedia definitions).

However, not all concepts could be presented in this way. Thus other ways of presenting new concepts efficiently were investigated.

3. SAVANT 2: A Multimedia Network System

SAVANT 2 is a multimedia server which was designed to allow access to short multimedia-interactive presentations of concepts. The system, which was operational in 1986, is organized around a centralized video server equipped with five videodisc players and a broad-band star network in optical fibers.

Multimedia (video+sound+overlayed videotext) is used here to increase the efficiency of narrative presentations. The student's control is at the sentence level: he may jump instantaneously from one passage to the next or to the previous one. But the use of video presented the opportunity to consider a more paradigmatic approach to narrative style.

There were several reasons to think that a good way to present a concept on a narrative media was to put it into a problematic situation. We designed a short (one minute long) multimedia clip for each concept to be presented. Each clip was structured along a systematic problem/solution pattern: the student was presented with a problematic situation which the new concept was able to solve. A problematic situation may be a logical inconsistency, or a technical solution having undesirable side-effects. These clips were very much appreciated by our students (over 60% were satisfied with this in evaluation questionnaires). So progress followed in that direction.

The idea that concepts had to be presented in a problematic context came from spontaneous conversation study [3, 4]. Conversations are indeed one of the only natural situations where concepts are exchanged. Since the main challenge of all the teaching aids lies in their acceptability, our choice was to copy a natural situation. We hoped to achieve this acceptance goal by making the student feel that s/he is involved in a kind of natural conversation.

Our first attempt was to offer a conversation which consisted of pre-recorded replies. Three characters could talk at each time, and the user had to choose who was to speak next. The different linking possibilities were, of course, known in advance. According to her/his choice, the student was following one dialogue out of a large number of alternative conversations; and at the end s/he will have learned much from this conceptual exchange.

At this point in the technical development of learning aids by the authors it appeared that concepts had to be explained in two different ways: through decontextualized definitions on one hand (e.g. SAVANT 1) and on the other hand through contextualized presentations, where the concept appears as relevant. This relevance requirement turns out to be a fundamental one. A relevant item either causes or solves a problematic (i.e. paradoxical or undesirable) situation, and the student understands and remembers the concept much better if s/he is puzzled by this problem. The next step was to offer the student the possibility of having a real conversation with the system. This was attempted with SAVANT 3.

4. SAVANT 3: Computer-assisted Didactic Conversation

Our fundamental hypothesis, which opposes the Skinnerian paradigm underlying traditional computer-based training (CBT), is that concepts and skills are qualitatively different and cannot be exchanged in the teaching act. The main difference becomes obvious in the case of errors. A student making a conceptual error needs more than a numeric or binary feedback; S/he requires a logical feedback [5]. To put it differently, using a computer metaphor, one could say that teaching a concept can be understood as making the student establish and modify logical clauses in her/his own knowledge base. Now it appears that argumentation underlying natural conversations turns out to be very well-suited to provide this logical feedback.

We designed a PROLOG program, as part of SAVANT 3, to sustain conversations about new concepts with students. This program makes use of a logical knowledge provided by an author. But the author does not have to be concerned with the strategy adopted by SAVANT 3 to argue with the student, since this strategy is straightforward and depends crucially on the student's arguments. Consider the following example:

M1 —Can a typed text be considered as a digital message?
S1 Yes.
M2 —But it depends on what symbols you take into account.
S2 Characters and punctuation marks.
M3 —But characters are not the only thing to be coded.
S3 Why?
M4 —But there may be a problem, if we consider that characters attributes (fonts, size, . . .) are to be coded.
S4 It works if we add special codes to the symbols.
M5 —Ah, okay! . . .

. . . .

The machine could have this conversation with the student by using rules like these:

- typed text is a digital message
- graphics and signature are to be coded
  ⇨ pixels are symbols
- typed text is a digital message
- characters are symbols
- fonts, size, . . . are to be coded
  ⇨ symbols are not limited to characters

These rules were supplied by the author who simply expressed logically what symbols may be in the special case of a typed text. But SAVANT 3 makes use of such rules in order to try to 'trap' the student in a contradiction. SAVANT 3 made here a first attempt by using a remark about the symbols taken into account (M2), expecting something about 'pixels' in order to activate the first rule above. But the student's answer (S2) led SAVANT 3 to consider the second rule, from which the student could escape with S4.

The SAVANT 3 strategy is quite simple, but it has many advantages. First, it is easy to implement, unlike systems which include multiple viewpoints [6] or systems which attempt to implement some philosophical theory of discourse like the Speech Acts theory [7]. Second, there are reasons to think that this system corresponds to what people do in real conversation [3], and thus the dialogue may appear more natural to the student than many machine dialogues do. Third, it seems appropriate from a didactic point of view. The logical argument (e.g. M4) provides the logical feedback which is needed when concepts are learned. This feedback has little to do with a binary right/false evaluation [8]. It is no longer possible to speak of exercise or error in SAVANT 3 dialogues. No choice made by the student is *a priori* correct or incorrect. The student is always invited to argue about her/his choices.

A knowledge base for a typical topic contains only 10 to 20 rules. Building and maintaining such local small knowledge bases, avoiding inconsistencies and redundancy, is very easy compared to that which expert systems require. It currently takes about three hours to carry out a dialogue with SAVANT 3's authoring system. We are developing a program which will allow any non-logical author to express the knowledge s/he wants to teach during a kind of conversation. The program will then translate this knowledge into a form that fits SAVANT 3 requirements.

SAVANT 3 is actually a complete system with a sequential narrative presentation (with graphics, videotext, digitized sound and video). It is linked to SAVANT 1 (local or distant encyclopaedia) and possibly to SAVANT 2. It also contains simulation programs, and all the necessary authoring modules. But its originality lies in the dialogue module which offers the student a natural way to discover or to check new conceptual knowledge.

In SAVANT 3 an attempt was made to combine different non-constraining teaching techniques: hypertext consultation, simulations, and free dialogues. Computer-assisted learning systems have, indeed, to be attractive to be accepted by students as daily working tools. We offered several systems to our students and hoped in each case that they would use them spontaneously. This goal was actually achieved with SAVANT 1 and 2. It has not yet been sufficiently tested with SAVANT 3. The conceptual content of technical courses, as well as the capacity of our students to learn by themselves, offered a good opportunity to try such attempts. But we have still to explore possible transpositions to other contexts.

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