The Computer as a Constructorium : tools for observing one's own learning

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Abstract

This chapter explores a particular form of the "transparency" concept: designing styles of interaction that explicitly reveal the pedagogical foundations of the ECS. Reflection tools and activities can help the learner to internalize an active model of learning. This model would emphasize the active, heuristic and negotiated nature of learning, by opposition to the school-made passive idea of what learning is. The system's model of learning cannot be accessed in an abstract way but only through the instantiation of this model by the learner's behaviour.

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1. The pedagogic facet of knowledge negotiation

Knowledge negotiation (KN) defines a particular style of interaction between a learner and an educational computing system (ECS). The choice of a particular type of interaction is a complex decision process based on knowledge about the domain, the learner and the pedagogical methods. The KN approach has its specificity with respect to each of these three components. We briefly describe the two first, the domain and student models, and develop this chapter around the third one, the pedagogical approach.

If we consider the domain model, KN tackles philosophical issues about the very nature of knowledge : the Platonic view of knowledge, that underlies the widespread idea of expertise, is progressively abandonned for a view of knowledge as the temporary product of social processes (Carley, 1986).

Concerning the student model, KN addresses some major criticisms made against current cognitive diagnosis techniques. It especially questions the possibility of representing the student knowledge as a perturbed copy of the expert's knowledge. Representing the learner's knowledge as a collection of partial models, potentially completely different from the expert's model, sometimes incompatible, selected and applied according to the context, finds instead a growing support in human psychology and artificial intelligence (Richard,1990).

This chapter will concentrate on the third facet of KN, i.e. the relationship between the KN style of interaction and the pedagogical decisions. The pedagogic approach determines the features of the learning interaction. In the particular case, the KN style is based on a constructivist view of learning, which implies that the learner tests her own representations in the learning environment. These statements reflect the designer's view : pedagogical decisions lead to some particular design. The learner observes indeed this relationship from the opposite point of view : **the interaction reifies the underlying pedagogical approach and hence conveys the designer's theory of learning**. This speculative chapter investigates a copernician move towards the learner's position. We explore a particular form of the "transparency" concept (Wenger, 1987; Brown, 1990) : designing styles of interaction that explicitly reveal the pedagogical foundations of the ECS.

2 . The learner's model of learning.

Children elaborate concepts that describe mental activities, such as knowing or remembering. For early children, these concepts often do not correctly match our understanding of these words (Wellman, 1985). For instance, pre-school children seem to consider that they "know" something when they give a correct answer, even if this answer results from guessing right (Misciones et al., quoted by Wellman, 1985). More globally, children tend to define mental activities by some associated external behaviour, they understand mental verbs as referring to observable behaviours. We are concerned by a particular mental activity concept : learning.

Learners have some representation of the meaning of "learning", here referred to as a "model of learning". Like other similar concepts, the childs representation of learning learning finds its roots in the observable activities labelled or considered as learning activities, i.e. mainly in school activities. Therefore, we must compare it with the representations that students elaborate from educational interactions. By the terms "model of educational interaction", we refer to the student's representation of any interaction which explicitly aims to promote learning for at least one of the subjects in interaction. The role of this model appeared in educational literature under the concept of "didactic contract" (Brousseau, 1980) : students and teachers tend to behave according to implicit rules they induced from previous classroom experiences.

The important assumption here is that these interactions are internalized into some representation of learning: "*The representations constructed by pupils of knowledge and the causes of success and failure in obtaining this knowledge are determined by the interactional and didactic context of the classroom*" (Schubaueur-Leoni and Bell, 1987). As

Lochhead pointed out, passive school experiences potentially generate a baneful representation of learning : "*Students tend to view learning as a passive experience in which one absorbs knowledge or copies fact into memory. Little of what they do in schools leads them to question that perspective.*" (Lochhead, 1985). University teachers may confirm this statement for students that have spent around 12 years in schools. The mechanisms by which educational interactions are internalised into some model of learning will be described in section 3.3.

The relationship between the learning model and the educational interactions model is not straightforward. Our representation of any event is closely associated with the context in which the event occurred (Tiberghien, 1986). Learners probably have context-related sub-models of learning interactions, and subsequently, contex-related models of learning. Research on mental models confirms this complexity. Humans do not handle a simple unitary model of the task performed, but instead some "distributed" model, i.e. a complex structure of partial models (DiSessa,1986). In "learning a poem", "learning to drive a car", "learning a foreign language", "learning to be happy", the word "learning" refers indeed to processes we perceive as quite different to each other. These differences result from the object learned (data, a complex skill,...), the domain (biology, mathematics, sport,....), the context (in/out school, with/without adults, ...) and the learner.

3. The "iconoclastic" principle

The adjective "iconoclastic" describes actions that lead to breaking an image. In our case, this image is the student's representation of learning. Our iconoclastic goal is to break the learner's passive model of learning. **The iconoclastic principle is articulated around the link between the interaction model and the learning model : if this link has been used for creating some model of learning, it can be reused in order to break this model**.

The rest of this chapter investigates how to implement this principle in an educational computing system.

This implementation is articulated around four stages:

- The transfer: the iconoclastic principle is only applicable if there exists a transfer mechanism from classroom situations to learner-computer settings; this transfer mechanism generates the learner's expectation towards the educational interaction she will participate in;
- The conflict : in order to deserve its iconoclastic title, an ECS must contradict these expectations by proposing a different interaction style;
- The constructorium : the ECS must offer activities that will lead the learner to internalise a better model of learning;
- The reverse transfer : if learners would bring their new model back in the classroom, then ECSs would get some potential to modify school practices, i.e. ECS would be considered as agents of innovation.

These four stages form a continuous and recurrent process, but they are now described separately and sequentially for didactic purposes.

3.1. The transfer from classroom to computer contexts.

There is an apparent contradiction in our discourse. We described mental models as partitioned in context-related subsets and we now postulate that students transfer the classroom-made model to settings where they engage in a dialogue with a computer. This contradiction may be overcome by analysing more closely the differences between the two contexts, the classroom and the workstation, and between the respective sub-models of learning. The context of learning activity is defined by various factors. Replacing the blackboard by a keyboard modifies one of these factors. Replacing the teacher by a computer and suppressing the other learners constitute more important changes. But on the other hand some factors do not change. The "scholastic" label of the activity often remains. Many scholastic concepts contribute to make the two contexts closer: exercises, errors, scores, tests, definitions, ... And finally, the distribution of educational roles is not modified : with most ECS, there is still an ignorant agent that has to learn and a knowledgeable agent that has to "communicate" (in Wenger's sense) its knowledge.

These similarities between learning in a classroom and learning with a computerized teacher (sometimes in a classroom) mean that there is some overlap between the learner's respective models of learning interaction. The extent of this overlap determines the transfer process. For instance, device-dependent features of behaviour will probably not be transferred : most learners know for instance that they cannot communicate with a computer by using the same language as they use with a teacher. But they may transfer more device-independent pieces of knowledge such as the necessity of systematic practice to reinforce newly acquired skills. Such transferable rules are more related to how knowledge is acquired , i.e. to the student's model of learning.

We believe that the standard ITS architecture facilitates this transfer process: in learning with an ITS, there is still an expert which knows what the student has to learn and there is still a tutor who knows what is the most suitable treatment for the student and who takes decisions about their learning. This architecture is in agreement with the role generally allocated to learners in the classroom. The presence of the expert component may reinforce the undesirable "copy" model of learning : if knowledge may be copied inside the computer memory, why not into the student memory? Learners would be right to wonder why they must reconstruct some knowledge which exists inside the computer in some inspectable form ?

Moreover, the probability of observing such a transfer process is increased by the general tendency to attribute a "mental life" to computers. This has been examplified in another domain by systems like Weizenbaum's ELIZA program or by Carfinkel's counseling system (Suchman, 1987). The later produced randomly "yes" and "no" answers to the users that believed however that the system performed some complex and intentional reasoning. A similar attribution process may be hypothesized about how students imagine the tutor's reasoning. This reinforces the hypothesis that learners transfer classroom-made models to the workstation context .

The Logo debate should be reconsidered in the light of this transfer process. Researchers have implicitly attributed the failure of free exploratory systems to the intrinsic limitations of learner's cognition. More precisely, these limitations concern the metacognitive skills involved in driving one's own learning. Learners do obviously have some limitations. However, we should take into account the fact that their attitude also reflects the effects of several years of passive schooling or, in our terms, that the attitude results from transferring to a new learning environment an inadequate model of learning acquired in the school environment. This complementary explanation is important for the design of systems. Instead of designing systems that compensate for metacognitive deficiencies by becoming increasingly directive, we should develop systems that support the learner's metacognitive activities (or, even better, that develop their metacognitive skills)

3.2. Creating a conflict

Didacticians have studied the (naive) representations that learners bring into learning and showed the necessity to jeopardize these pre-representations before trying to install new ones, otherwise the pre-representations reappear shortly after the lesson (Jonnaert, 1985). In order to encourage the abandonment of these pre-representations, the constructivist approach suggests that we should design activities which will reveal their inaccuracy The usual methodology attempts to generate an explicit conflict by asking the learner to produce predictions of some phenomena, and then running (or simulating) the phenomena and comparing the predictions to the actual results.

The student's model of learning may be viewed as a particular type of representation. Its specificity is that it does not concern the content of learning but the learning process itself. In order to jeopardize the learning-level pre-representations, ECS should present a style of interaction which clearly contradicts the student's expectations, based on their passive learning models.

The idea of knowledge negotiation has a some potential for creating a conflict with respect to the student's representations of learning. Usually classroom interactions do not show knowledge as something which can be negotiated (except in a few domains where the importance of personal judgment is well accepted). Another potential surprise is the fact that the system ignores what it is teaching. This is one of the hypotheses we explore through the design of a collaborative learning system (Dillenbourg and Self, 1990). At the outset, the computerized co-learner is a novice in the domain (electoral systems). It has some naive model of elections as its disposal and tries to learn by interacting with the real learner within a micro-world where electoral experiments may be performed.

Given the current state of the art we cannot generalise these features to determine some general technique for creating such conflicts. Designing iconoclastic styles of interaction is indeed a challenge for the creativity of the system designers. This challenge is made more difficult by the fact that these designers have themselves grown up inside traditional classrooms! Moreover, we have to be modest about the effects expected from of these conflicts. No system will in one hour destroy a model that learners have built and consolidated during thousands of hours. As a former teacher of nine years old pupils, I remember how some of these implicit behavioural rules were already very solidly anchored. Conflicts alone do not have the power to simply destroy the existent model of learning in a moment of miraculous insight. The complexity of the model itself makes it very resistant to change. It is more accurate to say that these experiences may extend the student's model of interaction and progressively move its centre of gravity towards a point where the student's active role in knowledge acquisition appears to be crucial.

In spite of the resistance to change, the disproportion between thousands of hours of classroom presence and a few hours with an ECS is somewhat reduced by two factors.

Firstly, not all classroom experiences reinforce the learner's passivity. Good teachers take care to vary the kind of didactic strategies they use, even for the same content. Secondly, in classrooms, the learning model is implicit and it is only its daily repetition that allows students to progressively induce some patterns. ECS may counterbalance their brevity of use by focusing on the learner's awareness of the activated models. This is the object of the next section.

3.3. The constructorium: integrating a new model of learning.

An ECS must include functionalities to promote the learner's awareness of its learning interaction characteristics and the internalization of these features into some (better) model of learning. We called such a system a constructorium (Dillenbourg and Self, in press). We have introduced this concept in our work on collaborative learning. In a collaborative situation, the communication between learners makes the learning process observable. A pair of collaborative learners constitutes a micro-society where one can observe the construction of knowledge, hence the name constructorium. In this sense psychologists create a constructorium when they observe peer interaction for collecting think-aloud protocols. The educational interest is that learners are also inside this constructorium and in some way may also observe the construction of knowledge.

In this kind of constructorium, learning as an intra-individual process is made observable by transposing it as an inter-individual process. It corresponds in some way to a reversal of Vygotsky's internalisation process (Vygotsky 1978).We want here to extend the constructorium idea to situations where the learner is alone. In this case, making learning observable means showing to the learner some representation of how they have learned.

The process of becoming aware of one's own knowledge or one's own cognitive processes, i.e. the "reflection" process, is a topic growing interest among the researchers on metacognition and among ECS designers. The use of computers for promoting reflection has been advocated by Brown (Brown 1985; Collins and Brown 1988). There are several techniques for promoting reflection. They have in common the techlnique of presenting some trace of the learner's activities and of the environment's responses. Systems such as Algebraland (Collins and Brown 1988) or the Geometry Tutor (Anderson et al. 1985) facilitate the learner's reflection by displaying the learner's solution path as a tree structure. This representation is not neutral but emphasizes some aspects of the learner behaviour. In these two systems, the heuristic aspect of the solution process is made apparent by the structure of the tree. We may describe this by saying that the interface reifies some abstract features of the learner's cognition. *Reification* means making concrete abstract aspects of behaviour, or, in Wenger's terms (1987), creating a written notation for a process. This practise is based on the assumption that metacognitive regulation is easier when it manipulates concrete objects instead of the abstract represented properties.

The design of tools for reflection is still an item on the research agenda for ECS building. If we want to build tools that reify the learning process, we need to represent visually how knowledge structures have evolved through experience and communication. Figure 1 shows a very simple example of representation that reifies the concept learning process (in the simple case of learning non-natural concepts such as quadrilaterals). This figure represents a learning session where the successive hypotheses expressed by the learner are noted in the columns and the various instances against which the learner tested the hypotheses are shown in the rows.

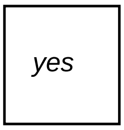
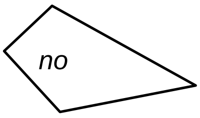
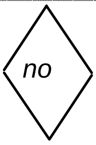
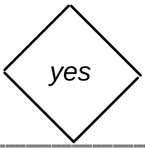
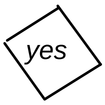
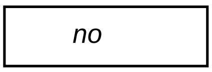
Instances / *Hypotheses*	**1** only vertical and horizontal sides	**2** four right angles	**3** four isometric sides	**4** 1 & 3	**5** 2 & 3
 *yes*	*yes*	*yes*	*yes*	*yes*	*yes*
 *no*	*no*	*no*	*no*	*no*	*no*
 *no*	*no*	*no*	***yes***	*no*	*no*
 *yes*	***no***	*yes*		***no***	*yes*
 *yes*		*yes*			*yes*
 *no*		***yes***			*no*

Figure 1 : A simple representation of a concept learning process.

(Bold rectangles indicate a mis-prediction)

This representation is arbitrary but reifies a simple principle of concept learning (and several other kinds of learning): each hypothesis must be tested and rejected if it mis-predicts the concept to which each instance belongs. A mis-prediction is represented by a small rectangle. Learning a concept does not any more appear as the memorising of some definition but as the process of actively testing one's hypothesis against a set of instances. Other features of concept learning can be reified in this simple representation, for instance the relative usefulness of instances, i.e. their capability to break an hypothesis, can be read in the columns.

Figure 1 is not presented as an universal solution but simply as an illustration of our ideas. Most important concepts suc as “democracy” , “insect” or “sentence” are more complex, their definition includes fuzzy attributes and some exceptions. In the systems quoted above, Algebraland and Geometry Tutor, the designers represented the problem solving process by a tree. We do not make a real distinction between learning and problem solving and hence think that trees structure are particularly suited to illustrate the heuristic aspects of learning.

In his work on metacognition, Schoenfeld (1987) uses a graphical representation of problem solving process that adds a temporal dimension to simple trees (but looses some other information). The purpose of this representation is to emphasize the active aspects of a mathematical problem solving process. The figures 2a and 2b show a representation of the actions of two problem solvers (or the actions of the same learner at different levels of expertise in problem solving). These representations are slightly simplified with respect to Schoenfeld's one. Each figure represents the time spent by the subject on the various stages of the solution process. The time is represented on the horizontal axis (20 minutes) and the solution stages on the vertical axis. Shaded areas indicate the time spent by the subject at some stage of the solution process.The subject represented in figure 2a is typically a passive problem solver. She decided to explore one direction and, during nearly twenty minutes, continued in that direction without ever considering another solution.

The subject represented in figure 2b explores a solution (stage "implement") but, after some time, she starts to feel that her solution will probably not be successful and decides to tackle the problem in another way (back to the "plan" stage). Each small triangle, absent from the previous figure, indicates a time when the subject said something like "How am I doing ?" and decided what to do next.

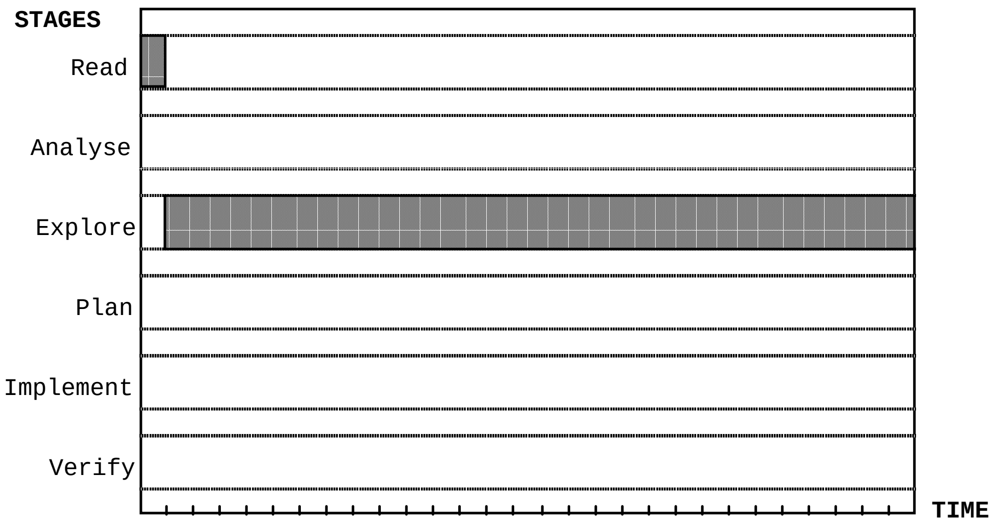


Figure 2a : Schoenfeld's representation of problem solving, the trace of a passive subject.

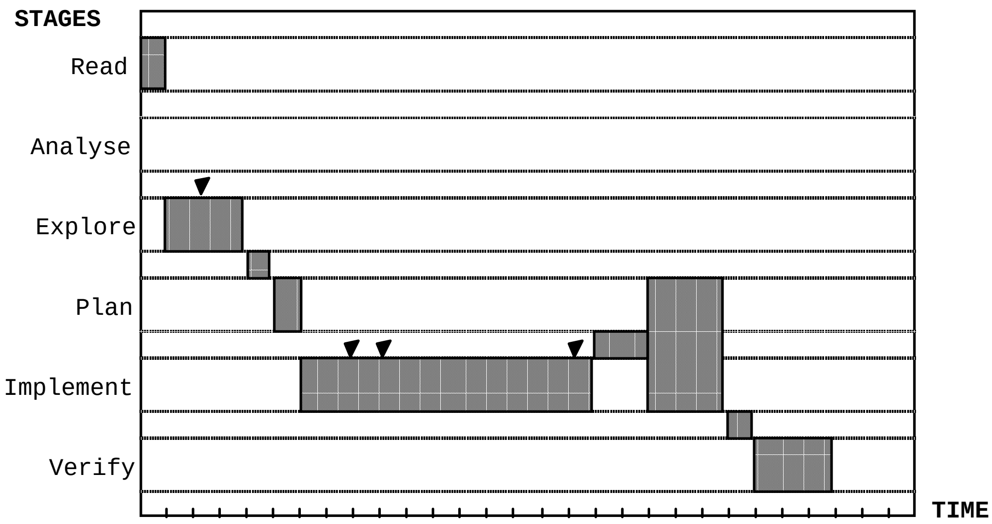


Figure 2b : Schoenfeld's representation of problem solving, the case of an active subject.

These figures are only examples. It is difficult to express in a general way what characteristics of learning have to be reified because they are largely context dependent. Moreover, this approach, although very promising, raises some complex issues.

The first issue concerns the *epistemic fidelity* of such representations (Wenger, 1987). i.e. the degree of consistency between the physical representation of some phenomena and the expert's mental representation of this phenomena. Assessing this epistemic fidelity is very difficult when the object represented is a concept as controversial as 'learning'. Moreover, we believe with Roschelle (1990) that representations should rather be assessed on their ***symbolic mediation*** qualities, i.e. their abilitiy to

> "...bridge the gap between commonsense and scientific interpretations of the world by providing an enriched physical situation to act in and talk about." (Roschelle 1990 PAGE REFFFFF?).

The scientific validity or completeness of the constructorium is indeed less important than its ability to conduct an interaction on metacognitive aspects of the learner's behaviour.

The second issue concerns the adequacy of the displayed representation to the actual learner's cognition, i.e. the *pychological validity* of the representation. Does the representation correspond to the way the learner is actually learning ? This psychological validity differs from the concept of epistemic fidelity. The former refers to the learner's knowledge while the latter refers to the scientific knowledge.

We here meet a dilemna frequent to ECS designers. At the outset the learner is probably not able to build this kind of representation. If the system builds it for them, then it may build something that does not correspond to the learning strategy used by the learner. This point becomes more forceful when we consider that a representation based on some virtual average learner probably does not cover a large variety of learning styles. This bias is not totally negative. Tt can be considered as a way of inducing a new learning strategy. The size of this bias depends on the validity of the cognitive diagnosis process implemented. It will be somewhat reduced by giving the advanced learner some tools to build her own representation. We imagine these tools as some kind of "cognitive MacPaint". In the case where the learner has to build a representation of her own learning, there is still a bias although it is indirect. The tools restrict the range of descriptions that can the user can draw. The availability of these tools should increase proportionally to the learner's task level skills because a more skilled learner can free cognitive resources in order to pay more attention to metacognitive reasoning. If the learner does not fully master the basic operations, we can speed up the process by adding system functionalities that perform these computations instead of the learner (as in Algebraland).

These statements lead us to the third issue : the learner's activities on the given representation. Does the display initiate any kind of metacognitive activities ? This basic question should be answered experimentally. However we may unfortunately expect a negative answer. The availability of reflection tools does not guarantee that users do indeed reflect on their learning experiences. We can only claim that the learner reflects if they perform some activities on the representation of their problem-solving. This issue is very important since the symbolic mediation function relates the display qualities to the activities performed on it. By comparing a few ECSs (quoted below), we have defined five levels of activities.

These are:

- *observing;* the learner just looks at the description;
- *editing*; the learner has some tools to edit the description;
- *orienting*; the learner uses the description to select a problem state;
- *composing*; the learner creates the description by combining items;
- *creating*; the learner builds the description from scratch.

If the interaction description is a tree, the levels of activities might be :

- *observing;* looking at the tree;
- *editing*; annotating nodes by justifications;
- *orienting*; selects a node for backtracking or ask for replay;
- *composing;* builds the tree from a bank of parts;
- *creating*; drawing the tree with lines and boxes

Editing activities are for example offered by Algebraland, while composing activities exist in TAPSII (Derry 1990). In this system on algebra word problems, the learners are invited to build a representation of the problem to be solved (and of the solution process itself). They build this representation by selecting problem schemas in a bank that includes a few schemas and instantiating the schema components with the data of the word problem.

When designing the learner's activitiy space, we have to keep in mind the global framework of this chapter. The challenge is to lead the learners to internalize some new model of learning. This process of internalization has been defined by Vygotsky :

> "Every function in the child's development appears twice : first, on the social level, and later on the individual level; first, between people (inter-psychological) and then inside the child (intra-psychological)" (Vygotsky 1978). PAGE REFFFFFF?

In the current case, the social level is the interaction with the ECS. Unfortunately, psychological theories fail to give much detail about the mechanisms of internalization. Vygotsky outlined the linguistic nature of these mechanisms when he declared that "...*verbal thought is the transferral of speech to an internal level....* " and that "*... reflection is the transferral of argumentation to an internal level...* "(Vygotsky 1981 quoted by Wertsch 1985 PAGE REFFFFFFFS?????). This linguistic dimension is important for our purpose since it emphasizes the relationship between the model of interaction and the model of learning.

Some precision about these linguistic aspects of internalization has been proposed by Wertsch (1985). He suggested that intra-psychological processes are sketched out at some stage of the inter-psychological level. By zooming on the semiotic processes of the inter-individual communication (including its non-verbal aspects), he reduced the discontinuity of the internalization process. Wertsch observed mothers monitoring their children solving a puzzle. He found that mothers change their referential perspective according to the child's skills. When identifying a piece of the puzzle, beginner's mothers refer to piece attributes that both agents can observe (e.g. "a green piece"), while later, mothers tend to refer to the strategical role of the piece (e.g. "a piece with the same texture as one you have already put"). Wertsch claims that the cognitive processes necessary for understanding the second type of communication are "... *virtually identical with the cognitive processes required to carry out strategic activities independently...*." (PAGE RFEFFFFFFFS???)

These findings correspond to the principle that underlies this chapter: the tutorial dialogue must refer to objects with respect to their role in the learning process. Figure 1 for instance emphasizes the role of positive and negative examples in rejecting wrong hypotheses. In this case the reference to the learning strategy was represented by graphics, but in more complex examples a short text could fulfill the same role.

3.4. The inverse transfer : from computers to the classroom

Until now, the success condition for most computer based learning (CBL) material has been its adequacy with respect to teachers' habits, to their curricula and to their teaching styles. In other words, CBL has been generally accepted when it did not promote innovation. Many teachers do not accept the loss of their central role within the classroom and hence use courseware as an electronic blackboard (that they can control themselves).

Some ECSs have the potential to break this loop. By temporarily changing teachers into advisers or collaborators, a system can sightly modify the classroom structure (Schofield, Evans-Rhodes and Huber, in press). This is a small but real change in the relationship between the teacher and the students. Recently, Schank and Edelson (1990) have outlined the innovative role of educational systems:

> "Rather than trying to reimplement our current educational system on computers, we must ask how we can use computers to reshape education in a way that is more effective and more relevant to modern world". (Schank and Edelson 1990 PAGE REFFFFFFFF?????).

We speculate that an ECS used as a constructorium might have some innovative power. If learners can internalize a better model of learning and transfer it to classroom situations, then ECSs will bring with them some potential for improving classroom practice. The question remains of how teachers will exploit this potential.

4. Conclusions

This chapter does not summarize long empirical studies. Instead, it raises questions concerning the acquisition and transfer of learning models and argues in favor of the following hypothesis: under some circumstances, the computer can promote the acquisition of some model of learning. The empirical validation of this hypothesis remains to be done. However, our speculative investigation of this idea raises interesting issues related to the concepts of reflection and transparency.

Brown (1990) pointed out that the learners should be provided with tools to build a model of the expert's reasoning and named this property "internal transparency". This chapter described a particular kind of internal transparency, some "pedagogical" transparency, that should give access to the model of learning (Wenger, 1987) that underlies the system design. In our large understanding of the word learning, the expert's reasoning may constitute a form of learning. Since an ECS is supposed to be based on some theory of learning, let the learner discover this model by transparency. However, this model cannot be accessed in an abstract way. It must be instantiated by the learner's behaviour. This raises the issue of knowing to what extent the instantiation of the system's model by the learner's behaviour corresponds to the learner's actual learning strategy. Transparency and psychological validity are closely related concepts (Wenger, 1987).

In this chapter, we also described the use of reflection tools for helping the learners to observe some model of learning through their own behaviour. The objects manipulated by the learner should be described by reference to their role in the learning strategy. By comparing these two last paragraphs, it seems to us that transparency and reflection are non-exclusive properties of glass boxes, or, in other words that an ECS can be compared to a plate-mirror.

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