Knowledge, the keystone of TEL design

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SUMMARY

This talk outlines the arguments supporting the claim that knowledge is the keystone of the design of Technology enhanced learning (TEL) environments. First, I consider the meaning we could attach to knowledge and knowing, and I introduce the notion of “conception”. Second, I explore how far the *problématique* of validation is central in our research. And to conclude, I introduce a characterisation of conceptions, which could help in addressing the problem of TEL design at a theoretical level.

Keywords

Epistemology, artificial intelligence, computational transposition, knowledge modelling, learner modelling, human-machine interaction, technology enhanced learning.

FROM LEARNER TO KNOWLEDGE, VIA LEARNING

The joint venture of education and information and communication technology (ICT) has first been led by technology and its promises. We all know what happened along the second half of the last century, all the expectations we had and the few success stories. One of the lessons learned from this first period is that the technology push is not enough, and that it is in no way a guaranty of success; whatever this word means. Introducing more advanced technology, importing in education more sophisticated ICT solutions, is not enough if attention has not been paid to the key objective of education: learning. So, after the technology push, the twentieth century ended with the learner driven principle of design.

Indeed, “learners” more than “learner” should be at the core of our *problématique*; the plural is needed since education is a social process as well as a process of socialisation. But this focus on the learners hides other users who are consubstantial to any educational project: teachers, trainers, institutions by several aspects, and also parents and the society at large. This may appear too large and too heterogeneous, and in the end of no help to solve the design problem that we have. This is right at first glance, but this heterogeneity is less important if one notices what all these have in common: learning. Indeed, whatever type of user we consider from the more central, the learner, to the more peripheral, the economical society, learning is the common concern. Learning—as an outcome and as a process—is at the core of any *problématique* of ICT in education.

Would it be possible to claim that the ICT user in education is "learning"? This seems strange, although it might be closer to what shapes research and innovation in our domain. The agreement we might reach on a "learning driven" principle for design of technology-enhanced learning (TEL) environments would in the end prove as disappointing as the naïve and initial focus on technology per se and the subsequent reaction by the focus on the learner. The reason why I suspect such a disappointment difficult to avoid is that learning has not a strong meaning unless we make clear its stake, that is: *knowledge*. Whatever learning we consider, it is the learning of a "something" which plays a key role. Just consider the learning of mathematics and of physics, the learning of literature and of surgery, the learning of chemistry and of philosophy. It is obvious, even from a common sense perspective, that these topics differs drastically either from a cognitive perspective or from an educational perspective. This help to understand that it is not learning which is central to our problématique, but the learning of something. Our research, our design, our innovation should not be "learner centred" but "learning something centred".

Although it may appear paradoxical—may be reactionary—to many of the participants in this conference, I would claim that after sixty years of research and R&D effort in the field of TEL, we are sent back to the understanding of knowledge. My claim is that understanding knowledge is a strategic condition for the development of TEL from a theoretical as well as from an operational perspective. Indeed, I don't mean that our research program would be to solve a problem that has been at the core of more than two thousands years of philosophy and epistemology. My objective is more modest. We need a pragmatic characterisation of knowledge in order to support our efforts to understand and to stimulate better design and on-the-field implementation of TEL. Pragmatic is here used in Popper sense, that is a characterisation which is relevant to our *problématique* although it will surely leave open most of the existing questions raised by this philosophical concept—but still ensuring enough coherency with what we nowadays know from cognitive sciences and epistemology.

Knowledge, as the keystone of TEL design will be the focus of this talk. First, I would like to clarify that knowledge—as I considered it here—is not an a priori given entity, to some extend well and definitely encapsulated in some text.

KNOWLEDGE, KNOWING AND CONCEPTIONS

Knowing: an emergent property of interaction

The question of the nature of knowledge (procedural versus declarative, formal versus pragmatic, etc.), the way it can be handled for the purpose of the design and the implementation of TEL, as well as the question of its representation for computational purposes is present everywhere. This question is made even more complicated by the need to develop a shared view of knowledge coping with computational constraints, psychological theories of learning, and educational theories.

Let us start from a very simple idea: the explicit aim of a TEL environment is to allow its user to learn some knowledge as the result of her/his interaction with a digital artefact. Although "virtuallity" is often mentioned in our domain, no body would deny that this artefact is physical. It could take the form of a computer with a keyboard, a screen and a mouse or a track pad, it could take the form of a PDA or of a telephone, and it could very often provide an access to a web of resources. In any case a TEL environment is a physical device with which we interact—we act and get feedback. Interaction is at the core of the design of learning environments; it should then be at the core of our characterisation of knowledge. In order to progress in this direction, let us tentatively summarise in the following table points that constitute a common ground.

Consensual principles for knowledge characterisation:

(i) Knowledge cannot be reduced to a text;

(ii) Learning is a dynamic process;

(iii) Learners don't receive passively knowledge, they are active constructors of meaning;

(iv) Errors are symptoms of the nature of learners' understanding;

Vergnaud (1992) principles:

(v) Knowledge originates in the need to solve problems;

(vi) Efficiency in solving problems is the criterion for knowledge to survive.

Table 1.

One should notice that the Vergnaud principles emphasise the existence of a fundamental link between knowledge and problems, and hence they call for a co-definition of both.

At this point, I may have to mention that expressing these ideas in English raises the difficulty of the epistemological tradition that underpins this language. “Knowledge” refers to both these intellectual constructs society has institutionalised and to those intellectual constructs that human beings produce as a result of solving problems or performing tasks. The former is often suspected to be fixed and static, on the contrary the latter is clearly changing and dynamic; actually, it is the latter that I have in mind here. While the English I know proposes one word, most languages of a Latin origin offer two possible words, which are in French “Savoir” and “Connaissance”; the former holds a rather static connotation, the latter relates more to the dynamic of understanding and of the construction of meaning. In order to recover this distinction, I suggest to use the word “knowing” as a noun, as the cognitive counterpart of “knowledge”.

But there is still a problem left. When taking a cognitive perspective, one quickly realises that even with reference to a precise piece of knowledge, a knowing is a complex multifaceted entity. The more surprising being that a single individual could evidence different and possibly contradictory knowings in different situations, depending on the context and circumstances, although these same situations could appear the isomorphic for an expert. In the beginning of the eighties the word “misconception” was often used to account of the specific way learners may attach different understanding to a specific concept; but what was much unfortunate is that a misconception was first the evidence of a wrong knowing… So, I suggest here to use the word “conception”, considering that a conception could be right or wrong, to name the contextual instance of a knowing.

To summarise, I use the noun “knowing” when I take a learning perspective, and the word “knowledge” when I take a teaching perspective (I mean a more institutional perspective. In order to give account of its complexity, I consider knowing as a set of its instances in different situations, and I shall call “conception” such an instance.

A “conception” has all the properties I mentioned in table 1. Its characterisation should account of the specificities of the learner, of the environment providing the context of the interaction and the type of tasks or problems that evidence its presence. A characterisation must account of all these aspects and their complex interactions. The characterisation of the conception cannot be encapsulated either in the discourse of the learner, nor in the characteristics of the environment, and surely not in the discourse of the teachers, trainers or designer stating the intention underlying the learning situation they designed.

Then, here is the proposed characterisation:

> A knowing is a set of conceptions. Each conception is characterised by the dynamical equilibrium of the loop action/feedback of interactions between a *knowing subject* (S) and a specific *milieu* (M) under certain *constraints*.

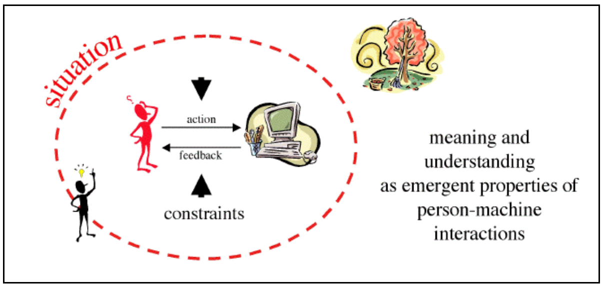


Figure 1.

In this characterisation, by "knowing subject" I do not refer to the individual with all its complexity, but to the individual under the polarised light of a learning stake; in other words the individual is seen from the point of view of the S/M *interaction* biased by the learning objective. Similarly, the *milieu* M is not the whole environment of the individual, but only the relevant part of it from the same point of view. It must be said that *M*, in the general case, may be a physical device, or an individual (possibly the subject itself), or a social body, or whatever else. The constraints determine the specific economy of the system.

Figure 1 evokes two other dimensions of teaching or training situations that I will not be able to develop here but which are as important as those I have decided to consider in this talk. First, the learning stake is related to the *a priori* existence of an object to be taught, second, the learning situation is organised with the purpose to stimulate and support the learning process. These two dimensions are essential to the understanding and modelling of any educational or training situation, but I will here concentrate on the seminal system S/M and the computer, which reifies the TEL *milieu* in relation to knowing and learning.

The view of *conception*, *knowing* and *concept* shortly presented here, has been developed within the framework of the *cK¢ model* which we are developing since about ten years and which support several of our projects (Soury-Lavergne 2003). I will use this framework to organise the way I address the questions I consider in this talk.

The aim of TEL research and innovation is to design and implement a digital environment, which could bring to existence a milieu M so that if the system S/M reaches some observable state of equilibrium it is then acceptable to pretend that the individual has learned (knows) some piece of knowledge.

Computational transposition and epistemological validity

Once some knowledge has been identified as an object of teaching or training, a series of adaptive transformations must be applied to make it teachable and learnable (what we call the *didactical transposition* following Chevallard 1985). However, once the content to be taught has been specified, other processes may again provoke transformation, especially as a result of the teaching itself, either because of the specific circumstances or as a consequence of the teacher or trainer own understanding of the content to be learned. In this framework, TEL introduces a new source of transformation of knowledge; it is this type of transformation that I will now explore.

First, let me take the time to consider the relation between a book and a film (a relation that we may expect to be close to that of a textbook and an educational software). Because the film must bring to real life the characters, the landscapes, and the action itself, then many decisions are taken, which introduce events not envisaged by the author of the book, and sometimes not even by the author of the film (think of this tree on the left hand side of the screen that no body else than you have noticed). Roman Jakobson called *transmutation* "this motion of a text across other media". In the same manner, TEL does introduce a transmutation of knowledge; now, a kind of computational transmutation.

I will hereafter evoke some of these transmutations.

Two types of constraints are quite classical and very often mentioned in computer science literature. They are *granularity* and *compilation.* Knowledge compilation and granularity bind the "inspectability" of the systems and their capacity to support the generation of explanations. From the beginning of research on Intelligent tutoring systems (ITS), the latter appeared of a special importance in an educational perspective (think of all the work around Guidon). But I would like here to point out other ones which could be of importance in our evaluation of TEL environments and which receive less attention in the literature.

Important decisions of implementation are related to management of time and organisation of actions by algorithms and then in actual programs. This management implies the introduction of explicit order where more often than not order is not expected or does not even matter. For example in dynamic geometry, all systems introduce an orientation (e.g. the segment AB is oriented because A is created before B). This sequential organisation may have spatial consequences in direct manipulation, but also in some cases "geometrical" consequences, as it is the case in the way the points of intersection of two lines with are considered and managed (this is a classical difference with important consequences between software like Cabri geometry and Geometer sketchpad).

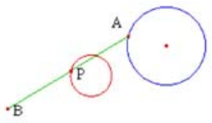


Figure 2

A characteristic example of this issue is the behaviour of a point, which has no other constraints than being on a given line. The issue is to choose how this point will behave when the figure is manipulated, but once this behaviour will have been chosen it will have both spatial and geometrical consequences (in particular in most cases the locus of this point computed by the machine is incorrect from a geometrical point of view—Balacheff 1993).

Let us consider the case of algebraic expressions like the ones we manipulate in elementary algebra, for example 5x+2x(x-3). These expressions can be viewed as strings of characters or as tree structures. To chose the one or the other fixes the kind of manipulation possible at the interface of the system. If the list structure is chosen, which is the case for pixie (Sleeman 1982), then the "buggy" transformation 5+3x —> 8x is possible, whereas it is impossible with a tree structure, which is the case of aplusix (Nicaud 1992). While considering such differences, we must realise that and pixie did not have the same teaching objectives (pixie focused on mal-rules diagnosis in elementary manipulation of algebraic formulas, whereas aplusix focused on strategies in solving problems such as factorisation). Indeed, both aspects are important from an educational point of view. Jean-François Nicaud summarises the specifications for such an environment in the following way: (i) it must "be linked to strong algebraic properties" but (ii) it must "allow the production of errors" at an editing and a reasoning level (while the software should provide relevant feedback to such errors).

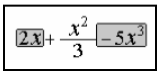
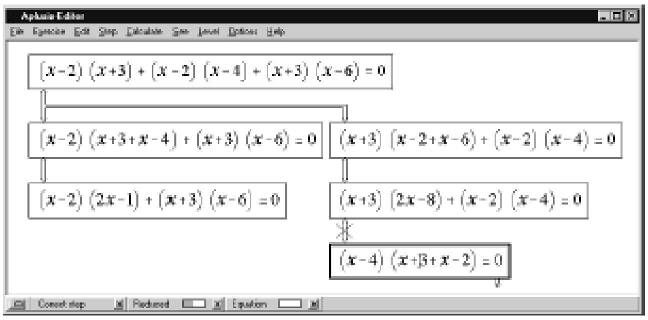


Figure 3

The new APLUSIX (Nicaud et al. 2004) includes both an algebraic editor with a feeling closer to hand writing but still coping with the structure mode of algebraic editing (thanks to a *text&box* mode at the insertion point) and allowing meaningful selections and *cut&past* (see Figure 3) and an editor for the algebraic reasoning (see Figure 4) which includes backtracking. This advanced editing is associated to *epistemic feedback* providing indicators about both the state of expressions and the correctness of the learner algebraic reasoning. The core of the feedback decision is the preservation of equivalence of algebraic expressions in the "replacement of equals" mechanism (crossed and non-crossed arrows in the Figure 4).



$(x-2)(x+3)+(x-2)(x-4)+(x+3)(x-6)=0$

$(x-2)(x+3+x-4)+(x+3)(x-6)=0$

$(x+3)(x-2+x-6)+(x-2)(x-4)=0$

$(x-2)(2x-1)+(x+3)(x-6)=0$

$(x+3)(2x-8)+(x-2)(x-4)=0$

$(x-4)(x+3+x-2)=0$

Figure 5

Although the design of APLUSIX is guided first by its conformance to algebra (its epistemic fidelity), it is important to notice that the modelling of feedback was not possible without taking into account of its possible didactical meaning. Deciding that a problem is solved in elementary school algebra is more often than not left to a tacit agreement (or *contract*) that the constraints of computational modelling evidence. Actually, such a decision depends on both algebraic (the syntactical correctness) *and* didactical criteria (the shape of the final expression must conform some didactical expectation). In the end, the designer decision includes a didactical transposition that interacts with the needed computational one (for this Nicaud coined new concepts, e.g. *factored concepts* and *solved concepts*).

Thus, the choice of a system of representation determines the kind of manipulations that can be made available to the user. It means that the feedback of the machine on the learner actions may differ from one environment to another, due to design choices and not to content characteristics. Indeed that could be the result of a clear decision, as in the case of APLUSIX, but this could as well be contingent to implementation choices as in some cases in geometry.

I called *computational transposition* the process that leads to the specification and then the implementation of a knowledge model (Balacheff 1993, but I now realise that "computational transmutation" would have been a better choice, although seen as too radical at that time). A large part of this process deals with the needed to fit the requirements of symbolic representation and computation, and the related transformation of knowledge. Reacting to what might be seen as mere (although complex) technological limitations, one may suggest alternative specifications or implementations so as to get rid of all these problems; but such suggestions miss the fact that other choices would just give rise to other unintended effects. The question is not to suppress them, since *any representation has productive effects*, but to be able to express precisely what they are and what could be their consequences in the case of TEL environments. Instead of searching for an impossible solution to avoid bias between representations and what they intend to represent, the way is to delineate the *epistemological domain of validity* of the chosen model or representation (Balacheff and Sutherland 1994).

An essential research issue is to understand the process of computational transposition, especially its intrinsic characteristics (the one which will not be modified by technical progress), and to develop theoretical frameworks and methodology for the identification of the epistemological domain of validity of TEL.

Eventually, a foundational postulate of our research domain is that *TEL design is domain dependent* because *knowing is representation dependent*. We are about to recognise that knowledge, as well as learning, is a constraint on the design of TEL environment. I will address briefly this point in the new section.

Knowledge specificity as a constraints

The characteristics of the milieu for the learning of mathematics, of surgery or of foreign languages are fundamentally different. Very shortly, one may say that the milieu for surgery is part of the "material world" (here, the human body), for foreign languages it includes human beings, for mathematics it is already a theoretical system. Although this observation seems obvious, most of the ICT research projects claim that they contribute to TEL research at a general level and they pretend to be domain independent. Even though, from a methodological point of view, they have developed no means and no theoretical framework to provide evidence for the validity of this claim. A devil advocate may say that ICT research does not see itself being accountable beyond the coherency and computing robustness of the software it produces, not to mention the constraint of re-usability often mentioned to justify the search or claim for domain independence. Although somewhat provocative, this statement does not betray an old trend which is still dominant today (possibly because of the strong economical stake of software reusability).

There is a movement towards more "pragmatic" approaches developing limited but efficient environments, although bounded by a certain domain of knowledge. There may be a the risk of developing a research based on ad hoc design and implementation in order to fulfil the constraints of “too narrow” topics. But this risk can be kept to a clear limit if the design is supported by a deep epistemological analysis of the domain considered, a solid documentation of the implementation choices and a clear view of the needed evaluation from a learning and a teaching perspective.

The knowledge constraints on the design of learning environments is directly related to the role played by interaction, I mean the action-feedback loop, and to the dependency of interaction on representation either “inside” the machinery or at its interface. I must insist here that the learning process can be achieved only if there is a positive evidence of the success of the loop action-feedback. This does not mean the success of “action”, but of the couple “action”-“feedback”: if M does not provide adequate feedback or if S does not make sense of the feedback from M, then the learning process cannot be achieved successfully. This remark points the role of control in the learning process, and beyond control the role fo validation. This could culminate in an explicit proving *problématique* (something that teaching of sciences and mathematics targets). Actually we may realise here that knowledge, or “knowing” in our terms, cannot be separated from the question of its validity and hence from the question of the possibility to “prove” (i.e. to produce a ruled argumentation) of its validity (it si on purpose that I don’t refer here to anything like “truth”).

Let me take, as an illustration, the case of physics and mathematics. The criterion for the validity of a statement in mathematics is somehow internal to this discipline; I mean it relies on techniques and a symbolic technology whose more achieved form is the (quasi)formal "mathematical proof". In physics, the validity of a statement is dependent on the relationships between the theoretical models and an "experimental field". The "experimental field" is the "field of validation of the theoretical construction […and…] it is the place where information is taken by direct perception of events or by measurements" (Tiberghien 1992 p.195). This field is a theoretically organised piece of reality, but it leaves to perception—under the control of the theory—a central place. This difference between mathematics and physics is crucial.

Such differences can be found between all the disciplines, they are the mark of their specificity but they are also the origin of the constraint they impose on the design of learning situation and, thus, on the design of technology enhanced learning environments.

Then, I offer to the discussion a new foundational postulate: *TEL design is domain dependent* because *learning is validation dependent*. This postulate is not easy to understand and even to accept (objections are often due to a misunderstanding of "validation" and "control", as a consequence of a kind of moral connotation). Then, our understanding of "validation", or of "validity", is critical to the design of TEL environments. It also binds our view of their evaluation. To understand it better, we must consider how learners are taken into account. It is this last point, a concluding one, which I will consider in the following section.

TAKING THE LEARNER INTO ACCOUNT

Behavioural versus epistemic modelling

The historical and technological milestones of in this domain are well known, from rule-based systems to machine learning techniques. But we must recognise that important difficulties have been encountered and are still resisting research efforts. However, the functions of the so-called student models in TEL environments, as well as their specifications, are not clear. As one of the leading scientist in AI and Education claimed: "the learner model is the central and yet most controversial component of intelligent systems" (Self 1990, p.46). One origin of controversies is the uncertainty about the psychological validity such models should have. The following considerations may help to clarify this issue: if the environment relies on dialogue and human like communication then a psychologically valid model may be needed, if it is essentially a reactive environment (i.e. a microworld) then to take the user into account on the improvement of the epistemic adequacy of the feedback it allows and not on its psychological validity *per se*. Actually, the only question is whether the way the learner is taken into account by the design is adapted to the need of the management of the interaction with respect to the content to be learned.

The problem of *taking into account the learner* has two faces. First, we must be able to characterise the kind of events that are relevant to describe his or her behaviours, second we need a function, usually called *diagnostic*, to ascribe some (formalised) meaning to these behaviours. The identification of "events" is not straightforward, it is the consequence of an organisation of the so-called "reality" under the control of a theory and its related methodology.

Once a model has been produced, the first question to address is that of its validity. On this respect the behavioural and the epistemic modelling are of a very different complexity. The *behavioural model*, when implemented in the same TEL environment, should allow creating at its interface the same observable "events" as those observed initially (the kind of criterion adopted by the Repair theory). In the case of an epistemic models it is expected that it provides a picture not only of the learner's behaviours, but also of his or her rationale in an acceptable way (at least from an educational perspective).

In the framework I have adopted, it means to be able to understand the student in terms of the *conception* we could ascribe to the state of his or her interaction, as an epistemic subject, with the *milieu* reified by the machine. What means that I take into account the student as a part of a system, and not as an isolated individual.

cK¢, a bridge between didactical and computational modelling

Confronting the tools and methods available in computer-science, to those available in educational research, one can see the large discrepancy in both the objectives of the models and their nature. A bridge is needed, and it is this bridge that I try to build with the model cK¢ shortly mentioned earlier.

To be relevant an epistemic model should provide an account of both the student behaviour and of its rationale, the related *conception*. For this, a model has to express the key features of the S/M system. Vergnaud shown that these features are the operators (R, the schemes in a psychological sense) and the semiotic systems (L, be it linguistic, graphical or embodied), both getting their full meaning from the existence of a set (P) of problems ensuring the conception legitimacy. This triplet (P, R, L) characterises a large part of the S/M system, it is complete when making explicit the structure (∑) that allows the control of S/M. As already mentioned, on both sides, either S or M, tools are needed to evaluate or judge the relevance of action or of a feedback.

Encapsulated in an agent (Soury-Lavergne 2003), the quadruplet (P, R, L, ∑) provides the framework for a computational account of the learner at an epistemic level. Given a problem *p*, (R, L, ∑) allows to compute a possible observable behaviour of the S/M system in the context of solving *p*, and unfolds the possible reasons of the behaviour by making explicit the underlying controls. The set (P) of the problems for which (R, L, ∑) leads to a correct solution (in a ∑ sense), characterises the domain of validity—the *sphere of practice*—of the related conception. It is the existence of this domain of validity that allows us to pretend that the modelling is at an epistemic level (table 1, item vi). Indeed, the characterisation obtained is specific not only to the learner (the subject S) but also to the TEL environment, which reifies the milieu M, with which he or she interacts; to understand it in educational terms is the matter of an other level of interpretation of the same evidences.

We are carrying out two projects in which cK¢ is the basic tool used to shape the way we take the learner into account. One of these projects, BAGHERA, has a tutoring perspective, the other one, APLUSIX, has a strong microworld perspective but explore the possibility to encapsulate learner models. In both cases, the semiotic systems available are those of the system interface and of the observable behaviours can be described at the level of granularity of the available commands. From these behaviours are inferred both the operators used and the related control. This talk is not the place to enter the technicalities of these approaches, so I will focus on the main benefit from the cK¢ approach and one of the lesson I have learned.

The cK¢ approach proved to be efficient in establishing the needed mediation between education and computer science by providing a common framework to discuss and analyse the learning processes and the related design. This approach made sense at a knowledge level and at a computational level. It stimulated a discussion for a better understanding of "behaviour" which definition appeared to be less obvious than a priori thought. Indeed, the key issue that appeared is the issue of the compilation of a sequence of commands into a so-called operator in an epistemic sense.

But more important is the lesson learned. cK¢ allowed to point the most difficult diagnostic problem: while the operators can be described as sequences of commands, the controls were much more difficult to describe or to characterize. More often than not, controls are left implicit, although they could have a reified basis like with the red arrow of APLUSIX (showing that two expressions are not equivalent). Within the framework of the analysis usually performed in education, based on the record of students' discourses and behaviours while performing a task or solving a problem, the controls are associated to *meta-cognitive statements* (judgements, adequacy of action, decisions of success or failure, etc.). The corresponding technique consisted of the search for the invariants of the context of action (what could take the form of <if *context* then *action*>), either using machine learning technique or the theory of emergence in multi-agent systems. In both cases, the task is rather difficult but not out of reach, at least it is the first conclusion of each project, in so far as the characteristics of the domain knowledge considered is well taken into account (i.e. through its intrinsic validation criteria).

REPRESENTATION, INTERACTION, VALIDATION

The concluding remark is that a critical survey of the problems of design of TEL environments invites to go beyond our usual focus on knowledge representation, and even beyond interaction, to reach the point where both converge to support and legitimate learning: control and validation. It may well be the case that the value of a learning environment rests in its capacity to support the learners' possibility to question the validity of their activity, and to support the system control of the learning process. In both cases the central issue is the issue of the feedback, which refer to a problem of validation. It is by this problem of validation that knowledge imposes itself as the premier character on the design scene.

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