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Abstract

Three main issues can be listed from the literature about computer-supported cognitive tools. Such tools are frequently evoked for improving learning, but seldom for assisting teaching. They are in most cases an application of an already-designed tool (e.g., concept maps) and models for designing new ones are lacking. Moreover, the underlying model of the activity of teaching they use is often function-based (i.e., a cognitive tool *for* teaching a given subject matter) than capacity-based (i.e., a cognitive tool for fostering *a given* teacher's capacity). We present here a model for designing computer-supported cognitive tools that aims at addressing these three issues. This model uses Popper's theory of knowledge, which is suitable for the design of knowledge-oriented tools. Three levels are successively considered in the design of such tools: the material world 1, the artifactual world 3, and the cognitive world 2. University students in instructional technology were given this framework and had to follow it for designing their own cognitive tool for teaching. An analysis of these tools shows that our model allows specifying a wide range of cognitive tools, without constraining the creativity of their designers.

Key Words: Instructional Design, Popper's Theory of Knowledge, Cognitive Tool, Teaching.

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Memory is a faculty of wonderful use,
and without which the judgment can very hardly perform its office.
M. de Montaigne, Essais, Livre II, chapitre XVII (C. Cotton trad.)

Recent literature in educational research emphasizes the use of computer-based learning environments as cognitive tools. Briefly put, some researchers consider that tools are the core function of the environment (e.g., Lajoie, 2000) whereas others (Clarebout & Elen, 2006) define tools as non-embedded support devices. The first lineage borrows the notion of "psychological tool" to Vygotsky (but see epigraph for an older reference to cognitive tools), for whom a tool is both social and artificial. The second lineage comes from the computer science notion of tutoring, in which the word "tool" is synonym with "system", and can be viewed as a utility. Since such tools are often designed and implemented without any reference to an educational context, they are considered as "outside the environment", thus their use is optional (Clarebout & Elen, 2006). It is worth noting that these two approaches are mutually incompatible. By definition, every tool is embedded within its environment, the possible user having the choice to use it or not, upon the degree of adequation of the tool for the task to be completed. Moreover, qualifying tools as "non-embedded" is to say that their use is optional, and most of cognitive tools (e.g., language, writing) are generally continuously used by human beings.

These subtle differences notwithstanding, the way the notion of "cognitive tool" is used in the literature raises three issues. First, cognitive tools are frequently evoked for improving learning (e.g., Lajoie, 2000), but seldom for assisting teaching. Second, they are in most cases implementations of already-designed tools (e.g., concept maps) and models for designing new ones are lacking. Third, the underlying model of the activity of teaching is often function-based (i.e., a cognitive tool *for* teaching a given subject matter) than capacity-based (i.e., a cognitive tool for fostering *a given* teacher's capacity). The aim of this paper is to propose an ID model of cognitive tools whose purpose is to address these issues.

Main Features of the Model

An ID model for the design of cognitive tools cannot be implemented without answering important questions: 1) from what viewpoint the instructional situation is considered?; 2) what is the theory of knowledge used?; 3) what precisely are cognitive tools? 4) how to formulate these questions to instructional designers? This section is devoted to the first three questions, while the next gives answers to the fourth.

In which Situation Instruction Occurs?

Several low-level activities are carried out during instruction. They provide an action grammar for describing every instructional action to be assisted by a cognitive tool. Instructional situations are composed of:

Events and Objects within an Environment... Teachers in their classrooms are confronted to many events (e.g., behaviours of pupils or colleagues) and objects, either intellectual or material. Each event can be analysed as part of an episode (i.e., the smallest set of events aimed toward a pedagogical goal) in which it makes sense. These objects and events are placed or occur within an entity called "environment".

…which is dynamic and supervised by a teacher… The main feature of the environment supervised by the teacher is its constant evolution. Some important variables of the environment like noise, attention or learning performance of pupils, can change regardless the intervention (and even the will) of the teacher. Thus, the latter has to maintain these variables within acceptable margins, like for dynamic environments supervision (e.g., plant supervision, aircraft piloting) which share complex features (Funke, 2001): uncertainty, opacity, temporal pressure, costly information, human errors leading to hazards, and so on.

…and uses heuristics or schemas to act… Teachers, as human beings, have a limited capacity for processing the information from their environment; moreover, they do not necessarily perceive all the information they may need. For making up these limitations and reducing mental workload, teachers have to plan actions, as well as to update their mental model of the environment regularly. More generally, their decisions can be consciously deliberated (deliberate choice among several options), but more often they are caused by the activation of action schemas (Schank & Abelson, 1977) or the use of fast and frugal heuristics (e.g., Chase, Hertwig & Gigerenzer, 1998). These procedures allow decisions with a low cognitive cost since they are based on minimal perceptual criteria.

… in an intentional way… Teaching is a formal intentional activity whose specific goal is pupils' learning (Noel, 1993), as opposed as education which is mainly unintentional and informal. The activity of teaching a given subject content is intention-driven: its purpose is to make knowledge intentionally built, and each intention-laden activity entails a design phase, in which goals, constraints, and desirable states of the environment are specified.

…with the help of some cognitive tools… Since knowledge is the main object managed in instructional situations, most of the tools engaged in teaching are cognition-centered. Two kinds of cognitive tools can be distinguished: material tools (e.g., handbooks, chalkboards, computers) and abstract ones (e.g., multiplication tables, procedures), and both

have the function of assisting (or guiding, amplifying, modifying, scaffolding, and so on) the cognitive processes carried out by their users.

…in order to foster pupils' knowledge building. Cognitive tools are designed and used for the main purpose to manage knowledge and foster its building by pupils. We develop now this last item.

Popper's Theory of Knowledge

We have now to define how knowledge is accounted in our model. We consider teachers and pupils as knowledge workers, and thus we argue that Popper's (1979) theory of knowledge is convenient for designing knowledge-centered tools. Briefly put, the entire human experience can be categorized into three worlds. The first one, called "world 1" is the material world (i.e., the world of matter and energy, including all living and inert forms). The second is the world of conscious experiences, called "world 2" (i.e., our perceptual experiences as well as our intentions). The third is the world of "objective knowledge" or "world 3", the objective content of scientific, theoretical, or cultural thoughts. This framework, as acknowledged by researchers (e.g., Bereiter, 2002), provides a useful way to think about the relations between knowledge content taught and the learner experience. Researchers (e.g., Sfard, 1998) showed that the acquisition metaphor do not properly account for learning. In other terms, learners do not actually *acquire* knowledge, as they would acquire an object by working within world 2, but more adequately they do *build* knowledge (i.e., they perform actual reconstructions of world 3), and, in consequence, they develop some capacities close to learning.

Provided that knowledge can be treated as an object, several actions can be performed about/on it (after Iiyoshi & Hannafin, 1998, ordered by growing complexity):

1. *Seeking and gathering knowledge*, i.e., supporting users to retrieve new and existing knowledge;

2. *Presenting knowledge*, i.e., helping users in presenting knowledge they encounter;

3. *Organizing knowledge*, i.e., helping users to interpret, connect, and organize knowledge meaningfully;

4. *Integrating knowledge*, i.e., supporting users to connect new with existing knowledge;

5. *Generating knowledge*, i.e., supporting the actual manipulation and generation of kwowledge.

Cognitive Tools for Teaching that Scaffold Basic Communicative Capacities

The main goal of cognitive tools is to support the use of knowledge in cognitive work (Dowell & Long, 1998), and to perform operations upon it: representing, transforming, converting, and so on. Cognitive tools are commonly immaterial and non-electronic (e.g., multiplication tables), although research paid recent attention to computer-supported tools (e.g., word processing, CSCL). Since a large body of literature describes how cognitive tools affect human cognition during teaching or learning, few ID models support the way to build new ones. For the sake of precision, we operate a distinction, following Simondon (1958), between "actual tools", which guide and control action and "instruments", which helps and enhance perception. In the same way, "actual cognitive tools" would guide teaching/learning performance whereas "cognitive instruments" would serve to assess knowledge of student performance.

Here we will reverse the common procedure which goes from the tool to the activity (for a given tool, what kind of activity can be supported?) to start from the activity to the tool. We describe the way to build tools that help the very cognitive activities performed during instruction, supported by some core capacities. We need for this purpose a rather large model that would account for instructional competence. We borrowed to Tomasello (2003) and to Hauser, Chomsky and Fitch (2004) some general capacities that ground language acquisition and that can properly be transposed to instructional purposes as well. Human beings usually exploit some core capacities, both innate and non-specialized (*i.e.*, domain non-dependent), allowing them to communicate to each others through language, which is indeed necessary in instructional situations, because it would not be possible to grasp complex notions (*e.g.*, pertaining to social, political or scientific domains) without language mediation. Thus instructional situations are essentially communication situations. Four general capacities can be listed as follows.

Understanding Communicative Intentions. One of the human beings' fundamental capacities is to keep interest toward intentions of their kind, and to try to guess them. In so doing they are engaged in communicative situations in which shared attention is directed to intentions (*i.e.*, thought contents). Instructional situations are precisely like such situations, in which teacher and pupils share attention to knowledge. Formal learning situations are often triggered by a generalized verbal proposition representing a rule, which is then applied to some transfer situations (Guberman & Greenfield, 1991). These situations differ from educative situations (*i.e.*, non formal) in which explicit rules are rarely elicited and transfer situations less frequent.

*Shared Attention***.** To be satisfactory, human communicative situations have to use another fundamental capacity: shared attention. Communicating, indeed, means not only understand, but also act on others' intentions. Communicating means keeping interest on attentional states of their kind in order to understand them and trying to modify them as well. A generic communicative situation is performed in a joint attention framework (Bruner, 1983), and is centered on the attentional states of the others. We postulate that each instructional situation is triggered in such a joint attentional frame, because both teacher and pupils direct their attention in the same object of knowledge.

*Cultural Learning***.** Human beings are particularly centered on culture and have particular capacities to acquire it. They find it interesting to match a given behaviour with a supposed goal to be performed. Through mimetic capacities, human beings can develop a particular form of culture that is easy to communicate to each other (Donald, 1991).

*Sensibility to Environmental Regularities***.** The fourth capacity consists of being able to detect visual or auditory patterns (i.e., regularities) within environmental events. As expressed by Tomasello (2003, p. 88) "[I]f a child [was] born into a world in which the same event never recurred, the same object never appeared twice, and the adult never used the same language in the same context, it is difficult to see how that child–no matter her cognitive capabilities–could acquire a natural language". We could add: "and how that child could ever understand the surrounding world". This core capacity is used in instructional sequences as well, when learners and teachers have to detect regularities to infer cognitive processes (learning) or intentions.

Description of a Model for Designing Cognitive Tools for Teaching

Once the theoretical background of our model has been described, we detail here a three-step instructional design procedure in which it can be embedded (roughly formulated in Dessus, 2004). As formulated above, Popper's theory can be adequate for our goal of characterizing cognitive tools, because computer-supported cognitive tools in instructional contexts are functionally a blending of three kinds of objects: material objects on which human action can be performed (e.g., a computer), theoretical (e.g., the course content, cultural procedures used in action), as well as cognitive events (e.g., learning, comprehension, knowledge building).

The designer has first to specify the world 1 level (either actual or virtual), which represents the material grounding of cognitive tools (see Figure 1 below). The most common object encountered in such tools at this level is the paper sheet, but some more complex material extensions are encountered as well (e.g., microworlds, school environment). The second step is about the world 3 level. Once the material background is chosen, artifactual schemes or cultural recipes supported by this material are necessary, because the sole material background is insufficient to provide adequate assistance for teaching or learning. Specific immaterial cognitive artifacts, like checklists, tables, grids, content to be taught, etc., have to be determined. The third step is about world 2. Once specified, the very goal of artifacts is to guide or foster cognitive processes, that is, not only to represent objects pertaining to world 1 (material) or world 3 (cultural), but also to implement or help some events of the human world 2 (in our case, events about learning and teaching). A large list of instructional events can be drawn, including course planning, student assessment, classroom management, etc. These events can in turn be supported by the four core capacities listed above.

1. *World 1* Objects	2. *World 3 Artifacts*	3. *Simulating or Assisting World 2*
Paper sheet Pupil desk School Environment…	Tabular form Check-list Course content…	Course design Classroom management Assessment…

Figure 1. *A Three-Step Model for Designing Computer-Supported Cognitive Tools.*

An Application of the Model in a University Course

Description of the Instructional Sequence

We carried out an instructional sequence using this model as part of a larger university course entitled “Knowledge and Technologies”. This course was taken by 9 second-year master’s students in educational sciences at Grenoble university. This sequence is composed of two theoretical courses exposing the aforementioned content (3 hours each) and two practical ones. The first practical course (3 hours) consists of a “hands on” sequence in which students have to understand the functioning of Latent Semantic Analysis, an AI model of knowledge modelling. The second practical course (3 hours) was devoted to designing cognitive tools, according to the prescriptions given in the next section.

Three colleagues taught the content of the three other parts of the course, which were respectively about – *learning tools* (how to categorize ILEs?; what are their effects on cognitive processes involved in learning?; collaborative learning with virtual environments); – *language learning tools* (main approaches in LLT research: sociological, ergonomic, communicative, and didactical); – *external representations* (the use of external representations in ILEs; ID principles governing external representations-based ILEs).

Description of the Design Task

During the second practical course, students had to perform the design of a cognitive tool of their choice (i.e., there was no constraint on the domain, the school level, and even the material form of the cognitive tool to be designed) following our model. Students were given a short description of the ID model, which roughly corresponds to the first section of this paper. Then they were asked to individually design their own cognitive tool for teaching (time given for the task: 1 month). A special emphasis was put on two important features of the design process: the specification of the basic communicative capacities especially fostered by the tool; the actual respect of the three-step procedure involving the three worlds.

The analysis of Students Productions

We analysed the main features of the tools (see Table I) our students designed by answering two main questions. First, what kind of cognitive tools (material form and type) were designed? were they centered on performance or knowledge (reported in columns 3 to 5 of table 1)? Second, what kind of core capacities they intended to scaffold (column 6)?

First, the material form of the cognitive tools, although mostly computerized, is diverse, ranging from paper-based MCQ to specification of constructivist ILEs (e.g., *The Math Adventure*). Moreover, the intended functions of the designed tools are equally actual tools or instruments. Four tools are devoted to higher levels of knowledge management (integrating or generating knowledge) while only one do not support any cognitive process (*Quiz*). Two other tools (*Writing and Spelling*, and *Vtext*), though not centered on knowledge per se, would allow the organisation of proposition in order to compose an essay. From a teacher viewpoint (cf. column 5), all tools are either centered on knowledge or performance.

Second, concerning the core capacities to be scaffolded by the designed tools, only two tools (*Quiz* and *Assessing Internet Searches*) do not specify any of these capacities, while others specify one or two of the four.

More generally, we can note that the designed tools can simultaneously viewed as "actual" tools for learning (i.e., helping action) and instruments for teaching (i.e., helping teachers assess pupils' knowledge building). This rough analysis shows that our model allows specifying a wide range of cognitive tools that are well documented and do not constraint the creativity of their designers.

Discussion

Current ID models typically address a unique form of complexity: they are either focussed on teaching, knowledge, tools, or capacities involved in instruction. For instance,

Table 1. *Main Features of the Cognitive Tools for Teaching Designed by Students during our University Course.*

Cognitive Tool (School Level)	Short Description of Pupils' (Ps) and Teacher's (T) tasks	Material Form	Function for Learning	Function for Teaching	Core capacities
Quiz (1st)	Ps fill in a short MCQ on a given subject. T assesses answers and fills in a grid representing the Ps' acquisitions.	Paper-based questionnaire	No cognitive support	Instrument of knowledge	None
Assessing Internet Searches (2nd)	Ps define and perform search queries about a given subject and the relevance of the web sites found is assessed. T provides help in all these tasks.	Paper-based assessment grid	Instrument for seeking and assessing information	Instrument of performance	None
Learning French Culture (1st)	Ps compare two cultures in analysing authentic situations by video vignettes, then they fill in comic strips. T guides and assesses Ps.	Software (ILE)	Tool for presenting knowledge	Instrument of knowledge	Cultural learning
Writing and Spelling (1st)	Ps write out essays with a word processor and are assessed (spelling, syntax). They then perform exercises proposed by computer.	Software	Tool for organizing knowledge	Instrument of performance	Communicative intentions
Vtext (university)	Ps write out an essay using a software that helps visualize and organize the text structure. T proposes outlines and different types of text units.	Software	Tool for organizing knowledge	Tool for designing sequences	Joint attention, Pattern finding
The Math Adventure (1st)	Ps solve several maths problems collaboratively in a cultural context. T has an overall visualization of the Ps' progression and gives advices.	Software (ILE)	Tool for integrating knowledge	Instrument of performance	Cultural learning, Pattern finding
Hand-Ball Video (1st)	Ps visualize and analyze hand-ball practice sequences for spotting good gestures and strategies. T monitors and assesses Ps' performance.	Movie camera	Instrument for integrating knowledge	Instrument of performance	Joint attention, Pattern finding
Historical Timeline (1st)	Ps place historical dates on a computerized timeline and be prompted with the assessment. Then they design timeline for classroom.	Software (simulation)	Instrument for generating knowledge	Instrument of knowledge	Joint attention, Pattern finding
Simulated Throw (2nd)	Ps perform simulated throws varying among several parameters (e.g., object weight, initial velocity, throwing angle), and infer the best conditions.	Software (simulation)	Instrument and tool for generating knowledge	Instrument of knowledge	Pattern finding

tylerian ID models are focussed on teaching while models inspired by Gagne are more largely focussed on knowledge. We attempted here to detail three forms of complexity and presented an ID model that simultaneously accounts for these three forms: complexity of instructional action; complexity of knowledge; complexity of communicative capacities involved in instruction.

Then we implemented an instructional sequence in order to test its usability. All students understood the main features of our model and designed various cognitive tools that were sufficiently sophisticated. They are both supporting high-level functions in instruction and are using core communicative capacities. We claim that two main features of our ID model allow the design of cognitive tools that are not based on already existent ones (e.g., concept maps). Since it is capacity-based rather than function-based, its use does not entail too much formal constraints on the tool design: our students designed tools with various material forms (paper-based, simulation, ILEs, enhanced word processors), as well as for various users. Moreover, the application of our model do not appear to be cognitively demanding: the three-step procedure gets designers respectively focussed on material, cultural, and cognitive aspects, each step adding a further constraint on the design of the tool.

Further research on this model will be twofold: first, we plan to verify to what extent each cognitive tool designed respects Popper’s theory of knowledge; second, we plan to apply a posteriori our model for analyzing or categorizing existent cognitive tools. More generally, the theoretical aim of this paper is to provide a new corpus of knowledge for instructional design. This activity has long been viewed as the one-to-one application of pedagogical scientific knowledge to the design of instructional situations. But, since industrial designers refer to their own corpus of knowledge (Dowell & Long, 1998), it is necessary to constitute a specific corpus of knowledge about teaching and instruction available to form novel ID models.

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