Introducing a representational tool of the trade in middle school

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Abstract: How to introduce computer-assisted design (CAD) as a representational tool of the trade in the classroom? This paper deals with the tension between the authenticity of design-based learning situations that is often strived at and the inherent complexity of the design process and CAD as a representational tool of the trade. We describe a three-dimensional framework for comparing innovative project-like scenarios in technology curricula to more traditional instructional sequences for science learning. We subsequently developed a dissociated geometry-oriented and an integrated technology-oriented CAD training and studied their influence on the way pupils engaged in a design task. Although the results show evidence of the complementary roles of different types of representations, no effect of type of CAD training is found. In the discussion, we propose potential explanations for these findings, by relating back to our framework, and make a suggestion for future research.

Introduction

In this paper, we develop the idea that creating conditions for learning about technology is essentially different from constructing situations for science learning. In our view, *technology* refers to the set of procedures and knowledge for imagining and producing artifacts, such as sewing machines, mobile phones, data processing software or algorithms for calculating interest, which are all objects, created by humans, to satisfy needs and extend capacities. Whereas the rationale of science is epistemic, the enterprise of technology is largely pragmatic and this may have important consequences for the construction of learning situations in those spheres of human activity (Vérillon & Rabardel, 1995). More specifically, *design* – in a way comparable to *research* in science – is considered to be the essential process by which knowledge grows in technology. Therefore, we take professional design situations as a reference for the construction of authentic learning situations in technology.

Design is about the construction of representations, internal and external, of a future artifact before its actualization and nowadays often takes place through computer modeling. Drawing further the parallel, in science, (computer) models constitute the intermediary between the theoretical and empirical level (see for example in Tiberghien, 1994). In technology, models constitute the intermediary between design and manufacturing (de Vries, Baillé, & Geronimi, 2006). Although studies on classroom design projects are emerging in the literature (Hmelo, Holton, & Kolodner, 2000; Lebahar, 2001; Roth, 1996), they have as yet not specifically focused on students' construction of design representations. In this paper, we present an inquiry into ways of introducing computer-assisted design (CAD) into the classroom as one of the important representational tools of the design trade. This presents an extraordinary challenge because of the complexity of these professional computer tools. Our secondary aim is to shed light on the relations between three dimensions of innovative learning situations corresponding to an analytic-synthetic, an epistemic-pragmatic, and an authentic-pedagogic distinction.

A three-dimensional space for characterizing learning situations

Design-based learning situations are an example of the project-like scenarios that have been developed for teaching in technology. The aim of such scenarios is to allow and encourage pupils' active participation in a sequence of organized activities with a specified goal (Lebeaume & Martinand, 1998). In order to distinguish these scenarios from traditional teaching sequences, we came to understand the orthogonality in principle (see Figure 1) of three dimensions of learning situations: nature, method, goal (de Vries, Baillé, & Geronimi, 2006).

The nature of a learning situation can be more authentic, resembling some professional practice, or more formal, pedagogic, specifically designed for learning (Lave & Wenger, 1989; Brown, Collins, & Duguid, 1989). It can have a more epistemic goal – acquire knowledge and skills – or a more pragmatic one – produce artifacts (Vérillon & Rabardel, 1995). They can be analytic – students need to decompose the full task into subtasks – or more synthetic – students need to recompose subtasks into the full task (Greeno, 1997). Traditionally, instructional design produced more epistemic, synthetic, pedagogic situations, such as teaching decompartmentalized knowledge and skills in science learning and evaluating performance by retention and transfer tests. Recently, there has been a rising interest in more authentic, analytic, pragmatic situations, such as in classroom design projects. However, we must keep in mind that it is possible to envision other combinations on the three dimensions, such as the designing to learn approach (Hmelo, Holton & Kolodner, 2000). In science, nature and goal are congruent for researchers and for learners: the authentic situation has an epistemic goal. In technology, according to Vérillon and Rabardel (1995), the pragmatic approach has to be applied by postulating that growth of knowledge is a result of acting upon the world. Such an approach reverses relations between knowledge and action, and authenticity can be achieved by focusing on material and semiotic tools. However, the difficulty with design and its associated tools of the trade is that it is not feasible to produce full-blown authentic, analytic, and pragmatic learning situations because of critical complexity of design tasks and tools.

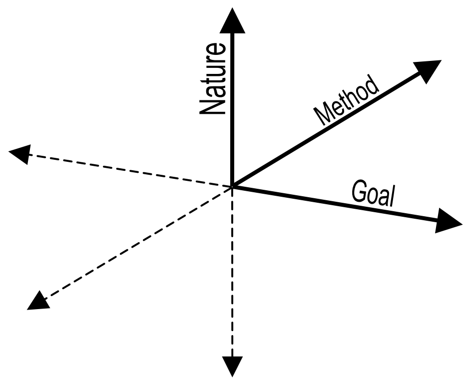


Figure 1. A three-dimensional framework for characterizing learning situations.

The notion of generic design

Goel and Pirolli (1992) argue that there are essentially similar characteristics of design tasks across domains and crucial differences between design and other cognitive activities. We stress three of the defining features as identified by de Vries (2006). First, design is a creative process; design problems are so-called ill-structured problems (Simon, 1973, 1981). Task goals have to be elaborated at the same time as possible solutions. As a result, design tasks, goals, processes and products cannot be described or prescribed in advance. Second, the ultimate design products are functional objects; they have to fulfill some need. Therefore, the form of the future artifact has to satisfy constraints related to manufacturing, use and maintenance. This articulation of form and function implies using knowledge from both the geometrical and technological domains. Third, design, essentially, is about the construction of internal and external representations prior to the making of the artefact itself: "An artifact is imagined and drawn at the same time; it is constructed through its representation and represented through its construction" (de Vries, 2006). Such design representations, both internal and external, have also been labeled cognitive artifacts (Visser, 2006). The external representations (i.e. texts, drawings, schemas, mock-ups, cardboard and computer models) of the future artifact play an important role in social professional interactions.

A representational tool of the design trade

There has been much research into learning with multiple representations and the use of interactive learning environments. Our work is about multiple representations, about constructing (rather than mere interpreting) representations, and about an existing professional tool (rather than one especially designed for educational purposes). The professional tool is used in its entire complexity from the start, which requires an instructional sequence in which students gradually get familiarized with its functionalities.

We developed a framework on mixed multiple external representations in design (de Vries, 2006). More specifically, constructing and interpreting design representations involves knowledge of three domains (Rabardel, 1989): geometry, technology and code. The *geometry* domain involves knowledge of the artifact's form in terms of concepts such as "cylinder", "cube", "tangent", and "concentric", as well as knowledge of projection techniques. The domain of *technology* concerns aspects that have to do with manufacturing, use and maintenance in terms of structures, components, behaviors and functions of the future artifact. Finally, the domain of *code* refers to knowledge of design drawings and discourse as representational systems, for example the association of lines, dots, patterns and their meaning in terms of material, shade, and spatial configurations. Nowadays, much of this third domain is taken care of by computer assisted design (CAD) programs. Because of its complexity, CAD needs to be introduced in the classroom prior to actually using it in a classroom design project.

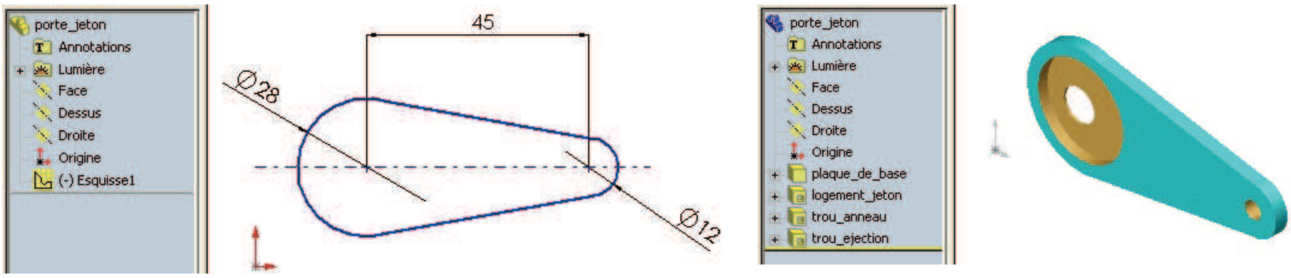


Figure 2. CAD example of part of a coin holder (left: 2D sketch, right: 3D model, with their construction hierarchies in French).

We use Ainsworth's (2006) framework for exploring the potential functions of multiple design representations in CAD. First, CAD allows *constraining interpretation* by familiarity that is by applying one's knowledge of one representational format to interpret a non-familiar format, or by the virtue of the inherent properties of representations. For example, in everyday life, descriptive texts and figurative pictures are comparably familiar, but they do not posses identical inherent properties. As Bertin noticed (1967), figurative pictures use an inherent spatial medium and descriptive texts use an inherent temporal medium. Thus, a picture might be used for spatial (graphical) constraining, such as when interpreting the sentence "the knife is next to the plate". And vice versa, a sentential description, such as "They had dessert and coffee", might be used for temporal constraining when interpreting a picture of a dinner table. In the case of CAD, a variety of representations coexist, namely two and three-dimensional CAD line and wireframe drawings, projections, renderings and animations, and a textual construction hierarchy (see Figure 2), which are all different appearances of an underlying mathematical geometrical model. In learning to operate a CAD program, the more familiar formats, for example renderings that look like real objects, can constrain interpretation of less familiar ones, such as for example wireframe models.

Second, multiple design representations *complement each other* regarding geometrical and technological information. Building a CAD model necessarily involves selecting geometrical aspects of the future artifact. A CAD program forces its user to obey to the laws of geometry, but it does not enforce technological constraints. Thus, you cannot create a geometrically impossible shape like those found in Escher drawings, but you can create models of unusable objects such as those found in Norman's design of everyday things (1988). Although some technological information can be represented in the construction hierarchy, such as functions of subparts of a model (e.g. base_volume, coin_space, ring_hole, and ejection_hole in French in Figure 2), CAD typically under-represents technological information and under-supports decisions regarding technological aspects. For example, one cannot know the appropriate size of an ejection hole before actually creating the object and trying it out in real-life circumstances. Moreover, one has to rely on another representational medium, some form of discourse, for representing decisions regarding manufacturing, use and maintenance. This type of discourse is more commonly known as design rationale: "A design rationale (DR) is a representation of the reasoning behind the design of an artifact" (Buckingham Shum, 1996, p. 95). Learning to design with (or without) CAD involves balancing the geometrical and technological aspects in the construction of external representations.

Third, the last function of multiple representations for learning relates to the idea that their combination and articulation *contribute to deeper understanding*. In some domains, such as mathematics (Duval, 1995), external representations are our only access to the objects and phenomena at hand. In science domains too, we rely on multiple representations, such as spectra, chemical equations, structural diagrams, electron dot diagrams, molecular formulae and computer models, for developing deeper understanding of objects and phenomena without being able to directly observe them (e.g. in chemistry, Kozma, Chin, Russell, & Marx, 2000). Design tasks can be considered another special case, since it is about imagining future artifacts not available for observation and manipulation. This process requires multiple external representations contributing to the full specification of the object before it can be manufactured and used (see also Gero & Reffat, 2001).

A study into design drawings and texts

Two main issues motivated the current study. The first issue concerns the difficulties encountered when introducing CAD in the classroom. We developed two different introductions to CAD use, focusing on either geometrical or technological aspects, taking into account the complexity of design tasks and tools. We paid attention to the fact that for use in actual classes, project-like scenarios need to meet a number of practical requirements. The second issue relates to the evaluation of the products of a design process. This cannot be achieved by a comparison of student-produced representations to some ideal solution; such a comparison would ignore the multiplicity of possible solutions, domains and representations. Moreover, traditional learning tests are incompatible with the authentic and pragmatic dimensions of the teaching situation since, in the real-life situation, the end products of a design process are not the texts, drawings, and computer models, but the object once it is manufactured so that one can evaluate its actual use. We argue however, that it is possible to gauge the extent to which the knowledge domains of geometry, technology and code have been invested in elaborating design drawings and texts. In other words, rather than evaluating learning in a strict sense, we administered a simplified design task to measure the extent to which pupils mobilize different types of knowledge as a manifestation of the way in which pupils deal with this type of task. The results then will allow to study the balance between types of knowledge and types of representations in design products and to answer the question as to whether type of CAD introduction influences this balance.

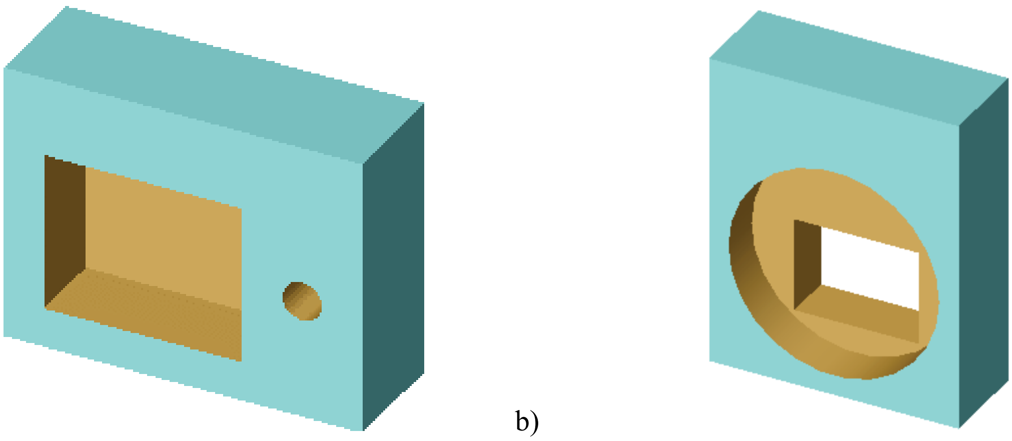
Method

The context

The study was carried out in a junior high or middle school (*Collège*) in the Grenoble suburbs. It involves six Eight Grade classes (age 13 to 14). The French national curriculum for technology courses at this level prescribes an introduction to CAD/CAM (Computer-Assisted Design and Manufacturing). Three groups, each consisting of two technology classes, were formed (36, 34 and 25 for a total of 95 pupils) that were sufficiently homogeneous according to the teachers. The different phases were approximately the duration of classroom sessions (alternating sessions of one hour and two hours).

The CAD training

Two different versions of a six hour CAD course were created: the integrated function-oriented and dissociated geometry-oriented training. The dissociated training consisted of a step-by-step construction of a model (Figure 3a) decomposed into elementary geometrical forms with familiar shapes and proportions without any mention of functional aspects. The integrated training introduced a technology context from the start by presenting the forms according to their functions (Figure 3b) without however disregarding the geometrical analysis necessary for CAD modeling.



a) Guided construction of the model of a rectangular box with extruded cuts, one from a rectangle and one from a circle.

b) Guided construction of the model of protecting foam with spaces for holding a CD-player and instructions for use booklet.

Figure 3. CAD models: a) dissociated geometry-oriented, b) integrated technology-oriented training

The design task

The following design task was given as pre and post-test: “The manager of a student residence has to decide upon the lay-out of the bedrooms. He disposes of a catalogue with available furniture. He asks you to help him. You have 40 minutes; you can use sheets, pens, pencils, eraser, ruler, scissors, and glue. Propose at least two different lay-outs using the pieces of furniture of your choice. Do not change the given dimensions of the room, its openings and the furniture. Look for possible lay-outs, represent them on the sheets of paper, explain every lay-out and give advantages and inconveniences.” A three-dimensional projection drawing showed the form and dimensions of the room and the available furniture.

Coding scheme

The coding scheme (Table 1) distinguishes between two knowledge domains, geometry and technology, and four knowledge types or levels: concept, function, behavior, structure. Both texts and drawings (see Figure 4 for an example) were segmented into the smallest meaningful elements allowing a classification according to knowledge domain and type. A blind coding procedure on 30 test texts and drawings was repeated with a three weeks interval and judged sufficiently reliable (Kappa = .87).

Table 1. Coding scheme for texts and drawings

	Domain		
Type	Geometry	Technology	
Concept		Propose arrangement	
Function		Target life style	Take into account givens
Behavior	Adapt to geometrical features	Define means and activities	Adapt to technical features
Structure	Geometrical composition	Choice of furniture	Technical composition

Procedure

Table 2 shows a summary of the study. All three groups completed the paper-and-pencil student residence design task (45 minutes). They subsequently had technology classes in which one group received the dissociated geometry-oriented training, one group followed the integrated technology-oriented training, and the third control group had regular technology lessons (a total of six hours per group). Hereafter, all groups completed the post-test in the same way as the pre-test. Student productions of both pre-test and post-test were scored for the number of geometry and technology units according to the above mentioned coding scheme.

Table 2. Summary of the setup

Pre-test – design task	CAD training sessions	Post-test – design task
Number of geometry and technology units in design texts and drawings	Dissociated geometry-oriented (n = 34)	Number of geometry and technology units in design texts and drawings
	Integrated technology-oriented (n = 36)	
	Regular technology class control (n = 25)	

Results and interpretation

In this section, we relate on the general accomplishment of this type of design tasks, examine the influence of type of CAD training, and investigate on the representation of geometrical and technological aspects in texts and drawings.

Prototypical design products

All (or almost all) pupils represented pieces of furniture in the two-dimensional drawing by indicating occupied space on the floor plan (category: geometrical composition in drawing), added the names of the pieces of furniture on the drawing and mentioned them in the accompanying text (category: choice of furniture in drawing and text). This corresponds to a minimalist understanding of the design task as a puzzle or mere brick game. However, we can infer that pupils took into account some user constraints, since there are no drawings with seemingly random positioning of furniture in the room which would have indicated a non-design strategy, namely *not* paying attention to functionality and usability at all.

Still, very few pupils (about 8%) represented technological information in the drawings, such as for example drawing a pillow on the bed as in Figure 4 (category: define activities in drawing). However, this same category appeared in about 74% of the textual productions. Pupils mentioned activities in their texts such as “rest”, “work”, “leisure”, “store”, “dress”, “move around”. Thus, the predominant interpretation for the student residence problem is one of choosing and placing furniture in both pre and posttest.

From this overall qualitative picture, it seems that texts and drawings are used to complement each other. Drawings are principally used to express spatial geometrical aspects; texts seem to be the more appropriate for expressing functional aspects.

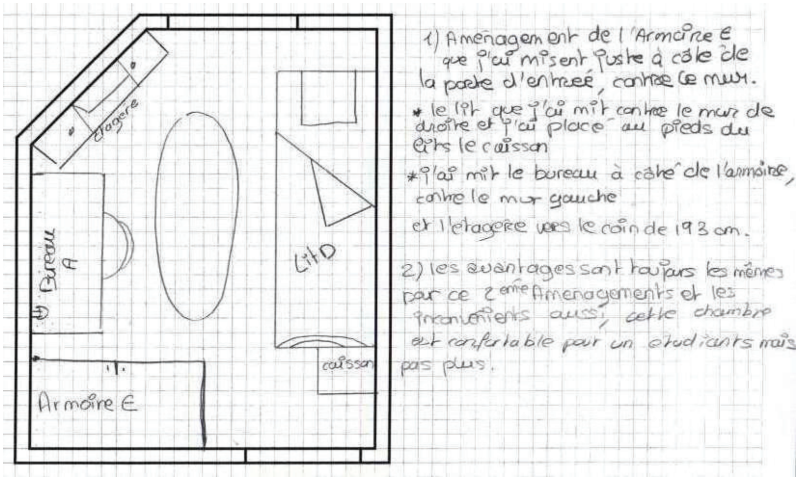


Figure 4. An example of a design drawing and text

Effects of CAD training condition

Figure 5 shows the total number of units in texts and drawings for both pretest and posttest. An increase in the total number of units contained in texts and drawings can be observed from pretest to posttest ($F(1,92) = 11{,}58$, $p > .01$). This can be considered a rather surprising result, since one might as well expect pupils to consider the task less interesting and challenging the second time; but they then would have produced less elaborate texts and drawings. Figure 6 also shows the results for each CAD training condition: the integrated technology-oriented training, the dissociated geometry oriented training and the control group. No effect of CAD training condition was found ($F(2,92) = 1{,}66$, *ns*), nor was any interaction with the other factors (time of testing, representation type, and domain). As mentioned above, the size of both texts and drawings increased from pretest to posttest for all groups.

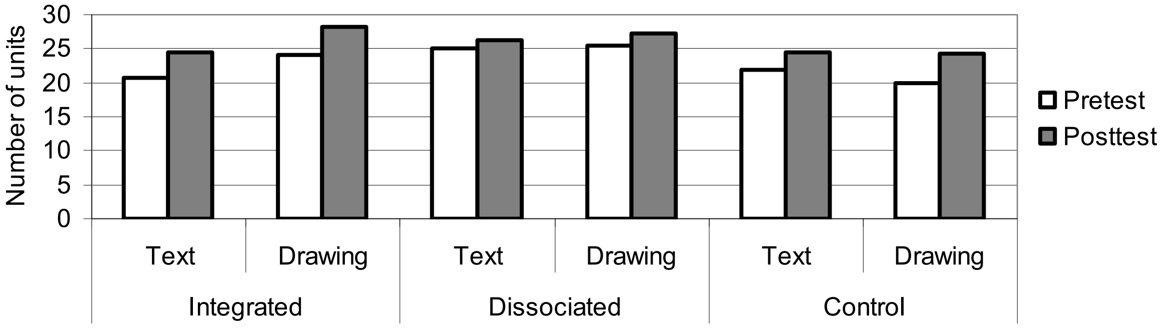


Figure 5. Size of text and drawings as a function of training condition and time of testing

Geometrical and technological information

We studied the complementary roles of text and drawing in representing information in the geometry and technology domain through calculating the total number of units. Figure 6 shows the means in pretest and posttest for each domain and each type of representation. The overall balance was in favor of representing aspects in the technology rather than in the geometry domain ($F(1,92) = 125{,}98$, $p > .01$), confirming the idea that pupils did not just consider this task a kind of a brick game. Moreover, the increase from pretest to posttest has to be attributed more to an increase in technological rather than geometrical units ($F(1,92) = 5{,}37$, $p > .05$). Finally, whereas the technology domain was more substantial in texts, drawings showed more geometrical units ($F(1,92) = 220{,}98$, $p > .01$), which constitutes quantitative evidence confirming our first impression.

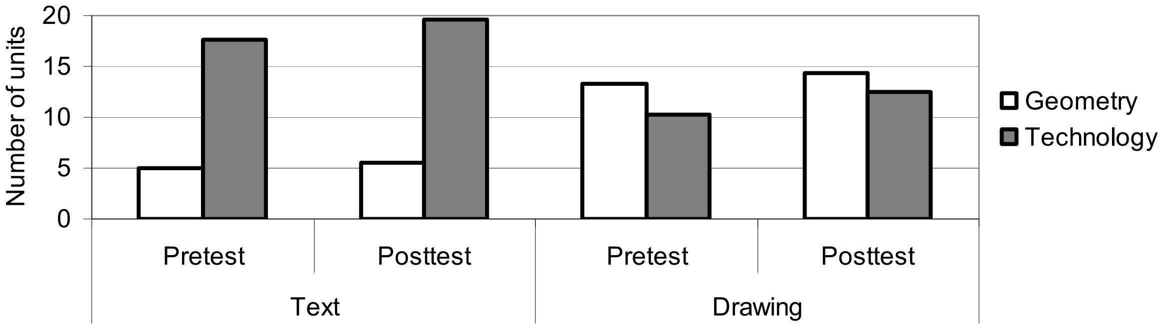


Figure 6. Complementary roles of texts and drawings

These results confirm the complementary roles of texts and drawings regarding geometrical and technological aspects. We speak of complementary roles rather than constraining interpretation since drawings and texts are equally familiar to the pupils. We could however consider it to be a case of constraining interpretation to the extent that it is also a consequence of the inherent properties of drawings – a spatial medium more suitable for geometrical aspects – and those of texts – a temporal medium that allows enumerating the functions that have been considered in elaborating the solution.

Conclusions and discussion

In this paper, we initiated an approach for introducing professional tools of the trade in middle schools as prescribed by the national curricula. We presented a three-dimensional framework for looking at these situations and developed two essentially different ways of introducing CAD as a representational tool of the trade in the classroom. The study showed the relevance of applying scientific knowledge of learning with external representations to the field of design-based learning situations. More specifically, students at this level produced elaborate text and drawings and managed, in addition to dealing with the geometrical aspects of a problem, to mobilize technological knowledge. Moreover, this particular design field lends itself to the study of students' production of multiple representations suitable for expressing different types of domain knowledge.

We found no impact of type of CAD training, nor could we differentiate CAD training from regular technology courses. We attribute these failures to an apparent contradiction when describing both the design task and the CAD training with the help of our three-dimensional framework. In fact, we characterize the design task as the more *authentic*, referring to a professional practice, *pragmatic*, aiming at the production of an artifact, and *analytic*, confronting learners with the complex task from the start. Due to complexity of the tool, the CAD training turned out to be more *pedagogic*, referring to a training situation, *epistemic*, aiming at the learning of a skill, and *synthetic*, learners execute a serious of actions in order to accomplish a task. However, focusing on the mere tools that are used in the two situations, the CAD training would, on the contrary, appear to be the more authentic, whereas the paper-and-pencil design task would seem to be the more pedagogic. As foreseen by Vérillon and Rabardel (1995), the design task and CAD training may have been experienced by the pupils as two entirely separated activities. Research in educational technology has also shown how teaching with complex computer programs, such as microworlds like Logo, Cabri and Tarski's world, carries the risk of students learning the program rather than the cognitive skills aimed at in the first place. In other words, when the computer tool becomes instructional content in its own right, the ultimate goals that founded the decision of its development and introduction get overlooked. Future research should concentrate on these dimensions, the positioning of particular project-like scenarios in technology teaching, and their effects on student design processes and strategies.

Finally, despite the fact that, on a computer screen, CAD models appear to be real objects; they are in fact virtual objects. As such, they embody both sides of the equivocal meaning of the term "model" (Bachelard, 1979): original and copy, archetype and exemplar, norm and figuration. Taking this into account, it might be beneficial to characterize CAD models in terms of an alternative typology of external representations for teaching and learning. Current advances on external representations for learning are accomplished mostly without questioning the *origin* of representational formats used in pedagogical material. For example, multimedia learning research relies heavily on figurative pictures and text according to the iconic-symbolic distinction. Most of science learning research focuses on existing representational formats (e.g. tables, charts and graphs), but also on domain-specific formats that have evolved as a consequence of the introduction of ICT (e.g. professional programs for designing electrical circuit diagrams). Finally, learners are nowadays also confronted with emergent representational formats, such as those used in graphical modeling languages and in visualization techniques. Future research founded on alternative ways of characterizing external representations, such as for example in terms of signification modes (de Vries, Demetriadis, Ainsworth, forthcoming), may shed light on the new field of the introduction of representational tools of a trade in the classroom.

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