European Journal of Psychology of Education
2005, Vol. XX, nº 4, 369-388

What animated illustrations conditions can improve technical document comprehension in young students? Format, signaling and control of the presentation

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We study the comprehension of a multimedia technical document about gear functioning by young pupils. The research is focused on the effect of three factors on the construction of a mental model: illustration format (animated versus static) signaling cues (presence versus absence) learner-control of information delivery (three rhythms of presentation: speed, slow and self-controlled). The experimental procedure, conducted with 123 children, follows three phases: pre-test, individual passation of the lesson, comprehension test, delayed post-test. The goal of the pre-test is the evaluation of prior knowledge about gears, but also the control of spatial and verbal working memory aptitude and reading performance. The results show an effect of the animated format, of signaling cues and of the rhythm on the immediate comprehension test and delayed test. For the immediate comprehension test, these effects are different according to the kind of comprehension question (recall, transfer, explanation). These effects are maintained at the delayed post-test, for the self-controlled condition and for the pupils with low prior knowledge. The factor information delivery rhythm shows an effect for the delayed post-test. Our observation device of the behaviour of the child during the lesson was specially designed to explore the reading strategies between the medias.

Introduction

Research about the effect of animated illustrations in the comprehension of multimedia documents has recently been developing (see the review by Bétrancourt & Tversky, 2000; Bétrancourt, Bauer-Morrison, & Tversky, 2001; Hede, 2002; Hegarty, Narayanan, & Freitas,

This cognitive ergonomic work was supported by a collaboration between the University Institute for teacher training of Burgundy at Dijon (IUFM), the LEAD-CNRS, and a project called "Makings of multimedia" whose partners (Town council of Dijon, Academic regional education authority, Hewlett-Packard and Microsoft) had the general goal to enhance "the daily use of computer in the classroom").

2002; Jamet, 2002; Mayer, 1999, 2001, 2002; Schnotz & Lowe 2003; Tversky, Bauer-Morrison, & Bétrancourt, 2002, and even more recently Ploetzner & Lowe, 2004 in the special issue of the journal "Learning and Instruction", 2004). However, the educational interest fostered by animations in learning started well before computers, especially with the use of movies as teaching aids (Mayer, 2001; Salomon, 1979, 1981). The results gathered in the experimental studies are not encouraging. Compared to static illustrations, animations seem far from bringing a significant improvement to comprehension or learning.

However, the positive effect of illustrations in the understanding of documents describing complex phenomena (for example how a pump works, or the phenomenon of thunder, Mayer & Moreno, 1998; Mayer, 2001) has been attested in numerous research (Mayer & Gallini, 1990; Mayer & Sims, 1994; Mayer, 1999; Ganier, Gombert, & Fayol, 2000; Hidrio & Jamet, 2002a; Hegarty & Just, 1993; Gyselinck & Tardieu, 1999; Gyselinck, Ehrlich, Cornoldi, De Beni, & Dubois, 2000). If and only if they are explicitly linked to concepts evoked in the text, illustrations enhance the construction of specific mental models (Johnson-Laird, 1983). It could therefore be thought that animations "naturally" possessed characteristics that are efficient to convey information on movements, on changes in time and space. But studies have come to contradictory results. The review from Bétrancourt and Tversky (2000) relied on the analysis of 12 experimental studies devoted to the comparison between static and animated illustration formats with the same content: only seven of them show an effect (often weak) of the animations. In a more recent analysis, Bétrancourt, Bauer-Morrison, and Tversky (2001) show that two main factors explain the better performance with animations rather than with static illustrations, or the absence of a difference. The first factor is the difference in the amount of information conveyed between the static and animated versions, that make too narrow the unique scope of the traditional research on the difference between static and animated illustrations (Ploetzner & Lowe, 2004). The second factor is the cognitive difficulty to process animated information.

The lack of information equivalence in static and animated illustration

Tversky, Bauer-Morrison, and Bétrancourt (2002) have shown that the better performances with animated presentations, when compared with static presentations could be linked to the nature and the amount of information to be processed, which differs with the type of presentation (Baeck & Layne, 1988; Rieber, 1990, 1991). The animated version shows all the micro-steps of the described process; and the static version usually only includes one illustration or the coarse steps of the process. Thus, the benefits could be due to the extra information included in the animated version. Moreover, in several studies (Schnotz, Boeckeler, & Grzondiel, 1999; Hegarty,Quilici,Narayanan, Holmquist, & Moreno, 1999) animated versions are more interactive than static versions; or, the learner has to make predictions on the behavior of the elements presented and a feedback is sometimes given. This last property, the interactivity, also explains the better performances.

However, the fact that the same information cannot be given in the two formats may not be a sufficient explanation. Most of the lessons used in research on animations do not only include information presented through pictures, but also through text. And, the text has physical (spatio-temporal) and semantic links with the animation. These links between visual information and textual information seem to be a major factor in comprehension, as Duval (1995) shows in a semiotic analysis on the convergence of different kind of written and graphical representations, or as Heiser and Tversky show (2002). The existence of these links is also shown in studies of experimental psychology on the co-referenciation of verbal and visual information, Jamet (2002); Schnotz et al. (1999). Finally, in other studies, animations do not allow better learning (Schnotz & Grzondziel, 1999; Schnotz, Bannert, & Seufert, 2002; Palmiter, Elkerton, & Bagett 1991; Palmiter & Elkerton, 1993) or only for experts (Lowe, 1999, 2004a).

A second problem is the nature of the information to be delivered. Bétrancourt and Tversky (2000) and also Tversky, Bauer-Morisson, and Bétrancourt (2002) claim that animations are useful when the information to be learned "includes a change in time" or a spatial transformation. Narayanan and Hegarty (1998); Hegarty, Narayanan, and Freitas (2002) have shown that to understand a complex mechanical system from an external static illustration, the learner focuses information processing on the mental simulation of a movement. We could hypothesize that when the construction of a dynamic mental representation is necessary to allow the construction of an efficient mental model (a "runnable model" for Mayer, 2001), then an animation helping with this cognitive elaboration should be better. Then, a dynamic illustration could be more efficient to explain concepts including a continuous transformation (a trajectory, limited in time, and entirely visible), than to explain concepts that only include the construction of different states (phases of an oriented process) with a beginning and an end (unfolding over a long period of time, by steps, not entirely visible). In this last case, the representation to be built should be related to the steps and the results of a process, and not to the trajectory. For example, animations could be more beneficial to present the functioning of a technical device, like a gearing system (rotation, direction, speed) than to describe biological phenomena like the transformation of a tadpole in a frog. For such contents, a succession of static images could be sufficient for the learner to reconstruct the development in time of the tadpole towards its end, the frog. This distinction seems to arise really when examining the results of the research compiled by Bétrancourt and Tversky (2000): the effect of animations is more stable when the lessons concern mathematics, physics (Newton laws, Baeck & Layne, 1988; Rieber, 1989, 1990, 1991) the functioning of technical systems, or action procedures (Kieras, 1992; Kaiser, Proffitt, Whelan, & Hecht, 1992; Mayer, 2001; Hidrio & Jamet, 2002b; Narayanan, 2002) than when the contents explain a longer temporal evolution towards a result, like the migration of embryo cells (Pane, Corbett, & John, 1996) the food chain (Kinze, Sherwood, & Loofbourrow, 1989) the development of bacteria (Lazarowitz & Huppert, 1993) or programming procedures (Palmiter, Elkerton, & Baggett, 1991; Palmiter & Elkerton, 1993) and more recently, Rouet, Merlet, Ros, Richard, and Michaud (2002). However, since an external animation has a high cognitive processing demand, it might not be the best way to produce a specific dynamic mental representation.

Perceptual and cognitive difficulty in animated information processing

A continuous and rapidly changing animation, which underlying structure is not revealed immediately, seems difficult to perceive and to process, given the limited perceptual and cognitive resources of any learner (Tversky, Bauer-Morrison, & Bétrancourt, 2002). Animations are not easily "apprehendable" (Bétrancourt, Bauer-Morrison, & Tversky, 2001) by the cognitive system and the student could find it difficult to extract the relevant information (trajectories, directions). Two other difficulties can be added: the learner must divide his attention (Mayer & Moreno, 1998) between the changing animation and the written text; and the speed of the unfolding animation is often too high, and different from the apparition of the different units of text. The animation speed could be ill adapted to the cognitive rhythm of processing and understanding of the learner (Mousavi, Lowe, & Sweller, 1995), especially when the learner is a child (Gombert & Fayol, 1988) or when the animation cannot be easily controlled. Despite the rapid growth of possibilities of interactions offered by new numerical tools, these characteristics are still present in a number of documentary encyclopedias used in schools and explain how "superficially" movement is processed, as research often points out (Lowe, 1999, 2004a; Bétrancourt & Tversky, 2000; Boucheix & Noël, 2000).

The perception of moving elements appears really difficult, so the cognitive system would preferably operate in a sequential way rather than to conceptualize directly a continuous movement. An external representation of a process by discrete steps could be more beneficial than an animation, because it could be more "naturally" compatible with the processing constraints of the cognitive system. It is possible that sequencing the presentation of information could be preferable in some cases to a dynamic presentation (Bétrancourt & Dillenbourg, 2002). Tversky, Bauer-Morrison, and Bétrancourt (2002) propose that the presentation of an animation should follow an "apprehension principle". This first principle is followed by an "expressivity" principle of the animation.

We can then hypothesize that a learning situation in which the student can control (stop, rewind, slow, etc.) the animation could be relevant to reduce perception and cognitive load difficulties. Several recent researches, with adults, about interactivity and animation control show a real benefit of such learning conditions. For example in a study realized by Mayer and Chandler (2001) with a multimedia material describing lightning, two versions of narrated animations are compared. In the first, the learner can have a simple global control ("just a click away") on the lesson, step by step. The second version of the lesson does not allow any control of the narrated animation. The participants who worked with the controllable version obtained better understanding performances (for transfer but not for recall) than the learner who worked with the fixed version. More recently with a procedural task of nautical knots tying from a video clip, Schwan and Riempp (2004) compared an interactive version (the video is entirely controllable: stop, rewind, slow) to a fixed not interactive version of the video clip. The results show that, compared to the fixed version, the interactive one produce a consequent reduction of the cognitive load and demand of the task (learning time). But control is far to always provide a real comprehension benefit. For example, if the deep understanding of an animation requires the acquisition of a prior knowledge about the abstract concepts underlying the superficial animated phenomenon, then a free control could be useless. A good example is provided by the studies of Lowe (1999, 2004a,b) about the cognitive processing of weather map in meteorology.

Another very important point concerns the detection by the learner, during the lesson, of the relevant information of the changing animation. This detection is uneasy for the novice pupils because of the unpredictable directions or trajectories. In this case, we can think that signaling techniques parsimoniously added to the delivery of the animated information will be benefit for the comprehension of complex animated systems. Such cues or signals could guide the learner attention in the direction of the crucial theme and toward what is necessary to look carefully at the proper time during the scrolling of the animations. Such signaling guidance could be a cognitive help for the explicit processing of the crucial dynamic information and to rate the comings and goings between the text and the illustration. It is what suggests two relatively recent researches realized with adults by Mautoné and Mayer (2001). These authors studied the comprehension of an illustrated lesson on how the airplanes achieve lift in three experiments. In the first an second experiment a version of the lesson accompanied by oral and written information (different of the concepts delivered in the lesson itself) which signal, organize or connect notions and part of the device (title, preview summary, sub-title, contrast of writing policy like bold, semantic connections like for example: "because, as a results") is compared with a version without signaling. In the third experiment others visual cues are introduced on animations: buttons, arrows, lines, color contrast, air movements). The results show that these signaling techniques improve significatively the comprehension. The effects was marked for transfer, problem solving and was more important with verbal guidance than with animated cues, see also, Shah, Mayer, and Hegarty, 1999. Huck and Floto (to appear) found a significant effect of non-verbal cues (arrows for example) on the illustrations of a biological lesson about the functioning of enzyme synthesis. But, these signaling techniques rise a problem: adding a lot of supplementary information, and this information really concerns a deep semantic level in the case of Mautoné and Mayer (2001, for example sentences like: "as results, because", the summary etc.), which encompass a simple signal. We think that to be both efficient and not too loading for the working memory, a signal should direct or guide the attentional focus of the learner toward the relevant look zone of interest (colored points, oriented arrows, blinking underlying) at the right time. Moreover, a study about gears and pulley system realized by Hegarty and Steinhoff (1997) showed that the spontaneous adding of annotations by the subjects during problem solving task (verification task) improve performance for pupils with low spatial aptitudes (see also, Heiser & Tversky, 2002).

At last, the studies of Lowe (1999, 2003, 2004b) on weather maps and of Schnotz and Grzondziel (1999) about an animated hypermedia about time zone system underline that to achieve a deep understanding with a static presentation the learner have to engage themselves in an active treatment of the system presented (mental animation). But the confrontation with a dynamic illustration could produce a less active involvement: when the illustration is dynamic, the animation is realized externally “instead of being realized by participants” which are then more “passive” (Fayol, 2002; Jamet, 2002). However, an alternative hypothesis can also be evoked. To start an active cognitive processing activity, a static format could be more efficient than a dynamic format only if the learner possesses appropriate prior knowledge on the dynamic movement to be anticipated, in other words, if he can elaborate spontaneously an internal dynamic representation from a static representation. Some young students may not have such sufficient prior knowledge and have more difficulty to engage themselves in a high cognitive level processing activities (Fayol, 1992; Hegarty & Sims, 1994; Hegarty & Steinhoff, 1997). On the contrary, these participants with low prior knowledge could benefit from the help of an external dynamic format, to engage in a real processing of the animation. If such is the case, animations should be beneficial when the prior knowledge of the participants on the theme studied in the lesson is low. But almost all of today’s research concerns adults and advanced students, who can have a high level of prior knowledge on the topics studied in the lessons, and not the child or the young student (except, Rieber, 1991; Ricci & Beal, 2002).

Goals of the study and hypotheses

The studies described before show mainly that the difficulties in using animations come from the conditions in which they are delivered. Therefore, we can think that (in case of adapted contents) controlling the rhythm of the presentation and giving signaling cues guiding the learner attention on the relevant elements of the movement could improve the comprehension on an animated document. In such conditions, a dynamic presentation could then be more beneficial than a static presentation of the same illustration. It should be benefit especially to the students having low prior knowledge. The experiment following in this paper was conducted to investigate these hypotheses, by testing young students’ comprehension of a multimedia document showing the functioning of a simple mechanical system. We have studied the effect on comprehension of the illustration format, animated or static, in function of the two factors that can influence the cognitive processing of the documents: signaling and rhythm of information giving. We have also controlled the level of prior knowledge of the students. This experiment was conducted with 123 undergraduates in seventh (n=48) and eighth grade (n=75) of primary school. The material consisted in a multimedia lesson on how work a gearing system: rotation of the gear wheels, direction, relative speed of each wheel and “mechanical effect”. We were especially interested in the effect on comprehension of the animated and static document of two modalities of signaling: presence versus absence of cues directing the student’s attention on specific areas of the illustrations, and in the effect of three rhythms of information giving: fixed fast/fixed slow/self-controlled.

We expect a beneficial effect of animations, when compared to a static presentation of illustrations. We also expect that a fast or non-controlled presentation rhythm will impede the comprehension, when compared to a self-controlled rhythm. The presence of signaling cues should also improve the comprehension performance. The effect of animations should be increased by the presence of signals guiding the attentional focus on the learner and also by a self-controlled rhythm of the course of the lesson. We have been careful to test, before the experiment it self, the level of prior knowledge of the students about the gearing systems by a pre-test, as well as their general verbal and spatial abilities. After the consultation of the lesson (experimental phase) we have used two comprehension tasks of the lesson to catch the possible differential effects of the manipulated factors: first, a task of immediate comprehension, and second, a post-test later in time (similar to the pre-test). We expect a different effect of the manipulated factors (animation, signaling and rhythm) on the post-test, depending on the level of the prior knowledge in the pre-test.

Finally, the device created to observe the learner during the experiment for this experiment (see below) allowed us to track the leaning time, and how the gazes of the child (oculo-cephalic movements) were distributed between the different media of the lesson, texts and illustrations. We expect the different experimental conditions to have an effect on the strategies of distribution of information taking.

Method

Experimental design and participants

The experimental design consisted of three factors plan: illustrations can be animated (AE) or static (SF); the signaling cues that guide attentional focus can be present (SP) or absent (SA); the lesson presentation can either have a fast (FR), slow (SR) or self controlled (CR) rhythm. There are a total of 12 modalities, each experimental condition (such as: animated, with signaling, self-controlled) includes 10 to 12 participants.

General procedure

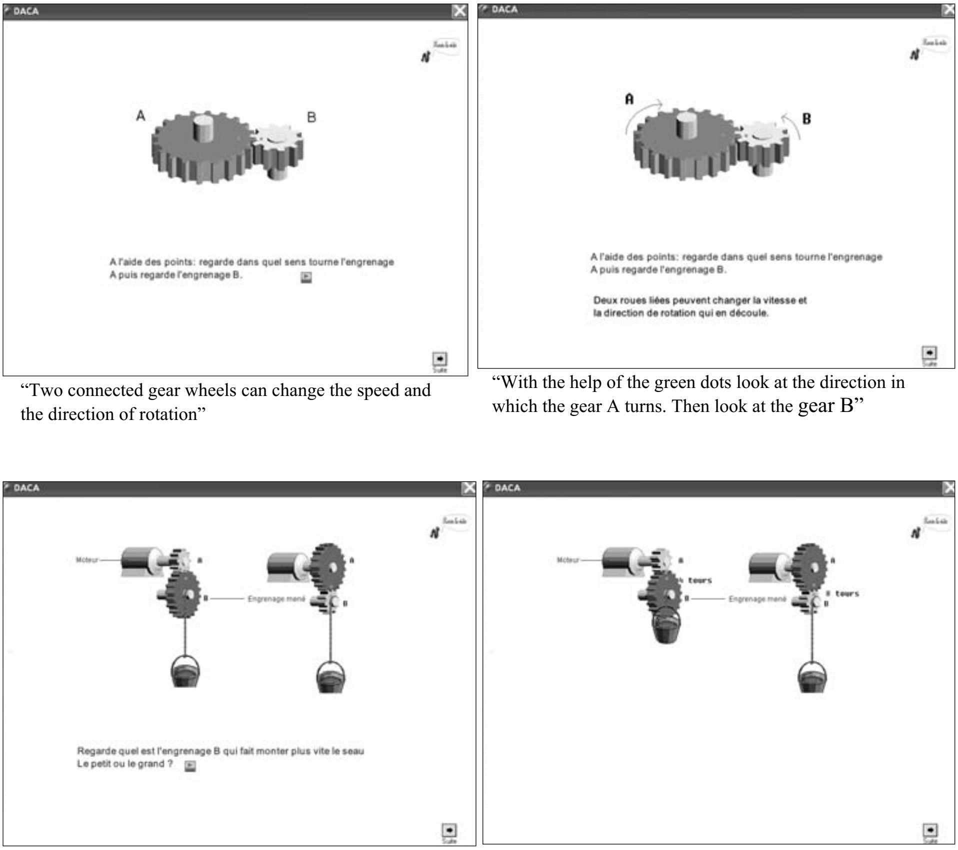
The experiment includes four phases. The first one is the evaluation of prior knowledge, and the control of general spatial abilities. This control is conducted in order to balance the different experimental groups. A collective pre-test on how gears work measures prior knowledge; it takes place about a week before the experiment (see below). The general abilities test includes a reading task, followed by a verbal and spatial working memory task. According to their level of performance at these tests (prior knowledge and general abilities) the students are organized in groups corresponding to the different experimental modalities.

In the second session of the experiment, students learn the lesson (individually on computer), and the third session consisting in the immediate comprehension test immediately follows (see below). Finally, in the fourth session, participants take the collective post-test on paper, so that the storage of the acquired knowledge can be evaluated later in time. This test is similar to the pre-test, and given about a week after he lesson has been learned.

Material

The multimedia lesson includes 19 slides. A relevant selection of images for this lesson is provided in Figure 1.

Each slide includes a picture of a gearing system with two wheels (and an motor), or two systems and a little explanatory text. Four main notions are successively explained in the lesson. The first one concerns the configuration elements of a gearing system (what a gearing system is composed of). The second notion is the rotation direction of wheels in a gearing system. The third one is related to the rotation speed of the wheels as a function of their diameter (number of teeth of the gear wheel). This third part of the lesson includes slides, each of them representing two gearing systems lifting a bucket full of water. Each gearing system is composed of two toothed wheels of different sizes, which positions are reversed from one system to another (see Figure 1). Finally, the fourth notion concerns the mechanical effect, i.e., the force engendered by the gearing system[1]. The text of each slide is composed of one or two sentences (maximum). After the task has been explained to him, the student is told that he will explain what he has understood and memorized of the lesson, by answering questions about the gearing-system. The whole lesson is consulted once. During the course of the lesson, each student is facing a computer. On the side of the computer screen we have positioned a fixed camera that is oriented to follow the student gaze, i.e. where the student looks and the movements of his head. Just behind the student, there is a blackboard. On the chalk-holder of the blackboard, a large mirror is set, where the content of the computer screen is reflected. Given the structure of each slide (illustration at the top of the screen, and the text below, see Figure 1) this device enables us to pick up efficiently the way the eyes of the students move (oculo-cephalic movements) between the text and the image. The time each student spends on the lesson is also recorded.



"Two connected gear wheels can change the speed and the direction of rotation"

"With the help of the green dots look at the direction in which the gear A turns. Then look at the gear B"

"Look at the B wheel which make the bucket going up the most quickly: the little or the big?"

(side to the B wheels) '4 turns' '8 turns'

Figure 1. The functioning of gearing systems: A selection of significant slides of the lesson (the text of each slide is translated below the picture)

Studied factors

Illustration format. In the animated condition (AE) the gearing system really rotate, and in the static condition (SF) it remains fixed. In the two versions, the test and the pictures are the same. Sixteen of the nineteen slides of the lesson can be dynamic. Sixty-one participants were placed in the animated illustration condition, sixty-two in the static illustration condition.

Signaling cues. In the condition where they are present (SP), four types of signals appear, across ten slides. The first one is a bright (green) color dot on each gearing wheel. The second signal is an arrow pointing towards where the wheel is rotating. The third set cues are tachometers, set next to each gearing wheel on slides concerning the notion of speed (Figure 1). Finally, the fourth type of guidance is a short sentence that encourages the learner to look at these signs every time they appear: for example, "look at the gear A" or "look at the two wheels A and B and compare their speeds". When the illustration is static, the instructions "look at…" are replaced by "imagine...". When the signaling guides are absent, all the cues described above do not appear. Sixty participants were placed in the signaling condition, sixty-three did not have any cue.

Control of the presentation. Among the three manipulated rhythms, two of them [slow (SR) and fast (FR)] are strictly time fixed and not controllable. The self-paced rhythm (CR) allows controlling the speed of the lesson: the pace of the presentation of the slides, and a partial control over the animations. To fix on the speed of the fast modality, we used the standard presentation speed of the lesson on gears in the traditional Encarta Encyclopedia, which is 1minute 40 seconds. In the slow modality, the presentation time is multiplied by three, 4 mn 10. Finally, for the self-controlled modality, the child follows the lesson at his own speed (with a little "next" button set in the bottom right-hand corner of the screen, see Figure 1) and can start over the animation (with a little icon set in the top right-hand corner). However, the learner cannot go back to the previous slide. Forty-two students were part of the fast condition, thirty-nine part of the slow condition, and forty part of the self-controlled condition.

Levels of prior knowledge. From the participants performances obtained in the pre-test, we distinguished three levels of prior knowledge: L1: low, L2: medium, and L3: high. Each level comprises a group of participants (see below).

Dependant measures. We defined four types of measure. The first measure is the performance at the immediate comprehension task. The second one is the evolution of the performance between the pre-test and the post-test later in time. The third measure is how long the participant took to complete the lesson. Finally, we consider the reading strategies by studying the eye gaze between the different media of the lesson.

Pre-test, post-test and immediate comprehension test

Pre-test and post-test. The pre-test includes 13 multiple-choice quetions and solving problem tasks concerning the notions explained in the lesson: the composition, the operation of gears: the direction of rotation, the relative speed, the engendered force. Each question asked comes with an illustration. The contexts of the questions (simple two-wheel gear, gear-wheels from bikes and bikers, carrying buckets of water, gearing systems with more than two wheels) and the types of problems to be solved are more varied than the situations explained in the document of the lesson presented before on the computer, and used in the immediate comprehension test. The questions asked focus on: naming parts of the gearing system (ex: *"on the picture, put an arrow where the gears are"*), indicating the direction the wheels will go (ex: *"indicate with an arrow which direction wheel B goes when wheel A revolves clockwise"*), ordering gears from a system, according to their speed, ("*in these gears order the wheels according to their rotation speed")*, calculating the number of rotations of a wheel (ex:*" A wheel has 20 teeth, and wheel B 10 teeth. If wheel A revolves once, how many times will B revolve?*), deciding which gear ratio will be more or less advantageous for bikers (ex: *"in which condition will it be the hardest for the biker to reach to top of the hill")*. The post-test is similar to the pre-test. In the pre-test, as in the post-test, each question (or part of a question, in the case of multiple questions) is coded as one point, each calculation only 0.5 point. The best possible performance is 19 points. We transformed each grade (on 19 points) as a proportion of correct responses.

Immediate comprehension test. Just after the lesson, each student answered orally (on an individual answer notebook, with figures and exercises) three categories of questions (for a total of fifteen questions). The first category was composed of strictly comprehension questions. Students were asked to recall the principles of gear operation: the composition of gears *(where is the motor?)*, the direction of rotation (ex: *"which direction does the wheel turn?*"), the rotation speed of the wheels (ex: *"which bucket will go higher with these gearing systems?"*). The second category of question were transfer (inference) questions on these notions used in similar contexts but slightly different from the ones used in the lesson, which required students to apply the operation principles of gears, in problem solving tasks. For example, there were questions on rotation speeds: *"In these two cases* (two pulley systems linked by cables operated by a crank) *Mr. Nose will only rotate the crank five times. The little dog Rox want to join his master the more rapidly as possible, which bucket should he jump in?"*, or on the strength generated by the system: *"Mr. Nose will rotate the crank as many times as needed to get his dog up, but he does not want to overwork, which bucket should he use?"*. Finally, the third category of question was an explanation phase for each notion of the lesson, the student had to justify orally his answers at the recall and transfer questions: *"Explain to me why?"*. Three grades were thus calculated: C – comprehension (6 points), T – transfer (4 points), E – explanation (5 points), with a total grade C+T+E on 15 points. We transformed each grade in a proportion of correct answers.

General abilities test

The reading test, called the "lark-test" by Lefavrais (1967), is an individual out loud reading task that is timed (max: 3 mn). This examination provides a global decoding (decipher) measure of reading ease. The results are graded along 5 levels: 1st-2nd grade, 3rd grade, 4th grade, 5th grade, and 6th-9th grade. We gave each student a grade out of 5 points according to the level they reached. This reading span is followed by a verbal span task. We adapted this individual task, with 10 items, for young students, on the basis of the task elaborated by Daneman and Carpenter (1980) for adults[2]. Each student has a grade out of 5 points (10x0.5). Finally, the spatial ability task (collective, with individual booklets) includes 36 items organized in 4 subtests. We have designed these subtests on the one hand from a spatial working memory task from Shah and Myaké (1996), and on the other hand from part of the spatial tasks of the Primary Mental Aptitude by Thurstone and Thustone (1964)[3]. Each correct answer is worth 1 point. The measures for each test are transformed in proportions of correct answers.

Results

After we checked that the performances of experimental groups were homogeneous for the factors controlled before the experiment, we will describe the results in three short parts. We will first examine the learning performances for the immediate comprehension task. Then, we will focus on the evolution of acquisitions between the pre and the post-test. Finally, we will present the data collected on the strategies of lesson learning.

Homogeneity of experimental conditions for the controlled factors

The ANOVAs performed on the scores obtained in the different control tasks (reading, verbal span, spatial abilities) and in the pre-test do not show any significant difference between the experimental conditions, as was expected.

Immediate comprehension

The mean proportion of correct answers for the immediate comprehension task, according to the experimental condition and for each of the three sub-tests (Comprehension C, Transfer T, and Explanation E) are recorded in Table 1. The mean scores for each factor (illustration format, guiding signals and rhythms) are presented in Table 2.

These results were submitted to ANOVA. Let's begin by describing the simple effects. First, the global score for the immediate comprehension task (C+T+E) is significantly higher in the animated illustration condition than in the static illustration condition [mAF=.63 and mSF=.55, $F(1,115)=5.04$, $p=.026$]. The presence of signaling cues also improves comprehension [*mSP*=.62 and *mSA*=.55, $F(1,115)=4.08$, $p=.045$]. On the contrary, the effect of the rhythm of presentation is not significant for this task [Fast *m*=.60, Slow *m*=.58, and self-controlled *m*=.58 $F(2,115)=.016$, $p=.84$]. Second point, the effect of animations and of signaling varies with the nature of the task implied by each sub-test: Comprehension, Transfer or Explanation. The animated version especially improves the performance precisely for comprehension [*mAF*=.76 and *m* SF=.68, $F(1,115)=4.75$, $p=.03$] with a single tendency for transfer [*mAI*=.69 and *mSF*=.59, $F(1,115)=3.04$, $p=.08$] but not for the explanations [*mAF*=.43 – and *m* SF=.37, $F(1,115)=1.5$, $p=.22$]. On the contrary, the presence of signal guides improves the ability to explain [*mSP*=.45 and *mSA*=.35, $F(1,115)=4.93$, $p=.03$] but neither the strict comprehension [*mSP*=.73 and *mSA*=.70, $F(1, 115)=.64$, $p=.42$] nor transfer [*mSP*=.68 and *mSA*=.60, $F(1,115)=2.13$, $p=.14$].

Table 1

Mean rates of correct answers in the immediate comprehension test as a function of each experimental condition and for each category of question

	Animated format						Static format					
	Signaling Pr.			Signaling Ab.			Signaling Pr.			Signaling Ab.		
(*N*=123)	Fast	Slow	Self	Fast	Slow	Self	Fast	Slow	Self	Fast	Slow	Self
C:	.79	.68	.80	.76	.80	.71	.70	.63	.79	.59	.70	.68
T:	.80	.66	.70	.59	.74	.65	.79	.50	.64	.57	.57	.51
E:	.51	.53	.50	.21	.51	.34	.41	.27	.51	.28	.42	.36
C+T+E	***.70***	***.63***	***.68***	***.54***	***.68***	***.57***	***.63***	***.48***	***.63***	***.48***	***.55***	***.53***

Note. C: comprehension; T: transfert; E: explanation.

Table 2

Mean rates of correct answers in the immediate comprehension test as a function of each factor (illustration format, signaling, rhythm) for each category of question

		Comprehension	Transfert	Explanation	T: C+T+E
Illustration Format	*Animated*	.76	.69	.43	.63
	Static	.68	.59	.37	.55
Signaling cues	*Present*	.73	.68	.45	.62
	Absent	.70	.60	.35	.55
Rhythm of presentation	*Fast*	.75	.62	.43	.60
	Slow	.70	.62	.43	.58
	Self-controlled	.71	.69	.35	.58

Let's continue by examining the expected interactions between the variables: animation, signaling and rhythm. The results show a single significant interaction between signaling cues and rhythm. This interaction indicates that the effect of the presence of signaling cues on comprehension performances is higher in the self-pace condition [$F(2,115)=3.65$, $p=.03$] than in the other rhythm conditions. On the contrary, unlike what we expected, we neither find an interaction between the illustration format (animated/static) and signaling [$F(2,115)=0.1$, $p=0.9$] nor between the illustration format and the rhythm [$F(2,115)=0.9$, $p=0.4$].

The evolution of acquisitions: the improvements from pre to delayed post-test

By means of the pre-test achieved before the experiment and the similar post-test later in time, it is possible to evaluate how the effects of learning on an immediate comprehension task are maintained or evolve in the more long term. According to our hypotheses, would these potential effects be identical, whatever the level of prior knowledge at the pre-test? To answer this question, we have started by distinguishing three levels of prior knowledge according to different levels of pre-test performances. The level L1 includes the proportions of correct answers between .05 (minimum) to .31, and is composed of 30 students. Level L2 includes the proportions of correct answers between .32 and .53, with 57 students. Level L3 includes the proportions of correct answers between .54 and .85 (maximum) with 36 students. For each of these three levels of prior knowledge, the mean rates of correct answers obtained in the pre-test and post-test tasks according to each studied factor (animation, signaling and rhythm) are presented in Table 3.

Table 3

Mean rates of correct answers in the immediate comprehension test as a function of each factor (illustration format, signaling, rhythm) and according to each level of prior knowledge

		Low – *n*=30		Medium – *n*=57		High – *n*=36		T: – *n*=123	
Prior Knowledge		Pre-test	*Post-test*	Pre-test	*Post-test*	Pre-test	*Post-test*	Pre-test	*Post-test*
Illustration format	*Animated*	.24	*.46*	.42	*.52*	.64	*.68*	.43	*.56*
	Static	.23	*.33*	.41	*.51*	.60	*.61*	.41	*.49*
Signaling cues	*Present*	.23	*.35*	.42	*.53*	.64	*.69*	.43	*.52*
	Absent	.24	*.44*	.42	*.50*	.60	*.60*	.42	*.52*
Presentation rhythm	Fast	.22	*.39*	.41	*.50*	.62	*.67*	.41	*.52*
	Slow	.26	*.35*	.43	*.53*	.63	*.64*	.44	*.51*
	Self-Cont	.22	*.47*	.42	*.53*	.61	*.68*	.42	*.56*

ANOVAs were performed with these data on the differences between pre and post-test. We will first present the simple effects of each factor and then the interactions. Considering overall conditions, we note a global effect of learning between pre-test and post-test $F(1,122)=73.1$ $p<.001$ (m – pre-test=.43, m – post-test=.53) plus an effect of prior knowledge $F(2,105)=15.05$, $p<.001$). The students improve more when the level of prior knowledge is low than when it is higher (however this result can also be to some extent the result of a ceiling effect for students with a high level of prior knowledge). A larger improvement of learning appears in the animated version of the lesson than in the static version [respectively .13 and .07, $F(1,111)=5.11$ $p=.02$]. The overall effect of signaling guidance is not significant, $F(1,111)=0.03$, $p=.86$. But, the rhythms lead to different significant gains [m self-controlled=.15, m slow=.06, m fast=.10, $F(2,105)=4.20$, $p<.02$]. It was not the same case for the immediate comprehension task.

Let's look at the interactions between factors. The positive effect of the dynamic version is more important in the self-controlled modality, as Figure 2 shows, $F(2,105)=3.11$, $p=.048$.

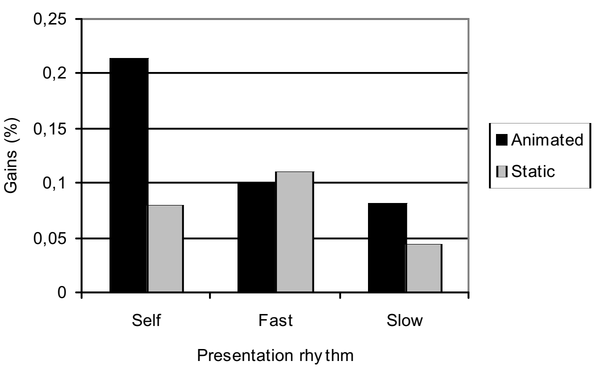


Figure 2. Mean rates of gains between the pre-test and the post-test as a function of the illustration format and of the rhythm of presentation

The signaling cues effect is not the same, when the rhythm of presentation varies $F(2,105)=3.48$, $p=.034$, Figure 3. Guiding signals have a positive influence on comprehension in the self-controlled condition whereas they seem to have a disruptive effect in the case of imposed rhythms, slow or fast ones. Finally, we do not observe any interaction between the illustration format and the signaling ($F(2,111)=0.1$, $p=.95$).

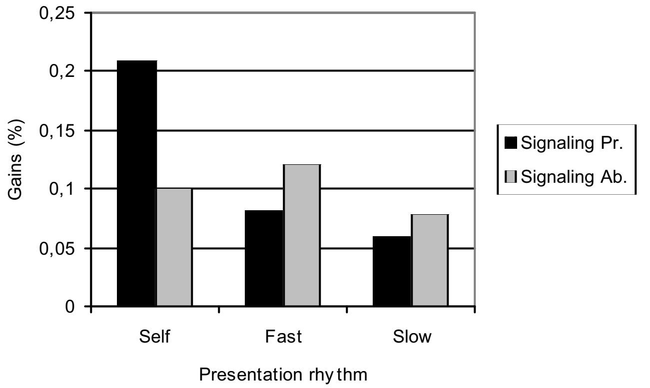


Figure 3. Mean rates of gains between the pre-test and the post-test as a function the presence (SP) of absence (SA) of signaling cues and of the rhythm of presentation

Concerning prior knowledge, we can note, on Table 5, that the superiority of the dynamic format on the static format concerns students with low prior knowledge. The interaction between illustration format and prior knowledge level is not significant [$F(2,111)=1.50$, $p=.22$] but a comparison between animated condition and static condition for the group of students with the lowest prior knowledge only (L1) is significant [$F(1,111)=5.86$, $p=.017$]. However, the presence of signaling cues seems to disturb students with the lowest prior knowledge, it is not the case for students having higher prior knowledge [$F(2,111)=3.40$, $p=.04$]. The students with low prior knowledge gain more from the self-controlled presentation, than from the two other rhythms. The interaction between rhythm and level of prior knowledge gives just a weak trend [$F(4,105)=2.33$, $p=.06$] but the comparison between the different rhythms for students with low prior knowledge only is significant [self-controlled *vs.* slow, $F(1,105)=14.08$, $p<.001$ and self-controlled *vs.* fast, $F(1,105)=6.54$, $p=.012$].

Text and illustration "reading" strategies

In this last part of the results, we will consider how long the lesson was read and the strategies of eye movements between different media. We have recorded in Figure 4 the means of reading time in the self-controlled condition, compared to the fixed times of the other rhythms of presentation.

The self-controlled rhythm ($m=391.23$ sec.) leads to a much longer reading time than the other conditions, even longer than the slow condition. The ANOVA performed on the reading times of the 39 students of the self-controlled condition shows a significant effect of the illustration format, $F(1,35)=13.24$, $p<.001$ (animated, $m=457.65$ sec., static, $m=328.14$ sec.) and of the presence of signaling cues, $F(1,35)=23.95$, $p<.001$ (with signals, $m=480$ sec., without signals, $m=305.8$ sec.).

For "reading" strategies, we counted (on the movie realized for each student, except for three of them, $n=120$) all the tangible gazes (oculo-cephalic movements) between the text and the picture, for each slide during the whole lesson. We did this counting for two separate parts of the lesson. The first part (definitions and rotation directions) included for each slide an image and a small text; the second part (relationships between wheel sizes and rotation speeds) included for each slide two separate images and a small text. Coding the number of gazes (oculo-cephalic movements) between the different media allowed us to word definition criteria for "reading strategies" that are presented in Table 4.

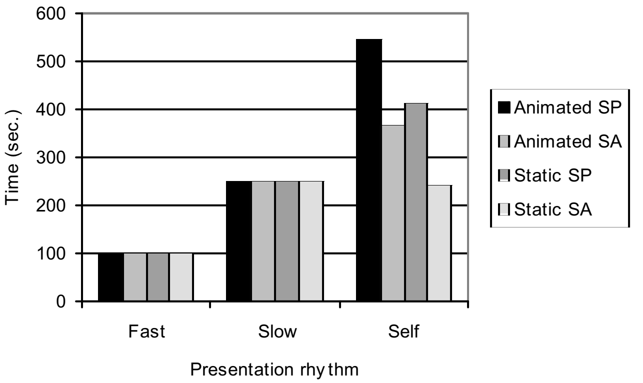


Figure 4. Mean times (seconds) of lesson learning as a function of the different experimental conditions

Table 4

Processing strategies of the document

Part 1 – Definition and rotation direction of the gear system

Three strategies are distinguished:

S1 In the group called "Illustrations" (I) the students use the main part of the time of exposition of the lesson to look at the picture, rather than at the text, *n*=12 students

S2 In the group called "Text-reading" (T) the students use the main part of the time of exposition of the lesson to look at the text, rather than the illustration, *n*=63 students

S3 In the group called "Shift text-picture" (S), the students alternatively move their gazes (oculo-cephalic movement) from the text to the illustration and/or from the illustration to the text, and thus distribute their gazes on the two media during the time of exposition, *n*=45

Part 2 – Size-speed relationship

Four strategies are distinguished:

S1 In the group called "global fixation" (GF) during the main part of the time of exposition the learners go directly to the written part of the presentation without looking at the illustrations, or they look undifferentially as much at both gearing systems, *n*=12

S2 In the group called "Text without comparison" (T+C-) during the main part of the time of exposition the students wait for the text to appear, do not look at the illustrations, and focus the instructions without comparing the two different gearing systems, *n*=28

S3 In the group called "Compare without (encoding the) text" (C+T-) the learners alternatively fixate the two gearing systems, but do not look at the text (or very little), *n*=27

S4 In the group labeled "Compare and (encode the) text" (C+T+) the learners systematically look alternatively at the text and at the two gearing systems, *n*=53

On the basis of these categories defined Table 4, we divided the students (percent) according to the different strategies used for each part of the lesson, for each experimental condition, Table 5.

Table 5

Distribution (%) of the students according to the strategies used to consult the lesson as a function of the experimental conditions

		Part 1 – Definition-rotation direction			Part 2 – Size-speed relationship			
		S1-I	*S2-T*	*S3-S*	*S1-GF*	*S2-T+C-*	*S3-C+T-*	*S4-C+T+*
Presentation rhythm	*Fast*	16	79	05	05	47	42	06
	Slow	08	50	42	05	05	18	71
	Self-Cont	05	26	69	20	15	05	60
Illustration format	*Animated*	16	36	48	04	14	32	50
	Static	05	67	30	16	31	14	39
Signaling cues	*Present*	13	44	43	00	22	21	57
	Absent	07	62	31	21	25	25	29

It can be observed that the different experimental conditions have an influence on the nature of the "chosen" strategy. The self-controlled version especially leads students to adopt more often than in other conditions systematic back and forth, i.e. "shifting" strategies between text and pictures. This is true for part 1 of the lesson [$\chi^2(4, n{=}82){=}37.15, p{<}.01$] as for part 2 [$\chi^2(6, n{=}82){=}56.9, p{<}.01$]. This shifting strategy is also more frequent in the animated condition than in the static condition, for part 1 [$\chi^2(2, n{=}120){=}12.71, p{<}.01$] as for part 2 [$\chi^2(3, n{=}120){=}13.15, p{<}.01$]. This tendency also appears when signaling cues are present rather than absent, for part 2 [$\chi^2(3, n{=}120){=}18.57, p{<}.01$] but not for part 1 [$\chi^2(2, n{=}120){=}3.62, p{>}.10$].

Discussion

The goal of this research was to examine, in young learners, the conditions in which animations could improve the comprehension of a technical document describing a dynamic process: the way gears function. We especially studied the effect of signaling and learner-control over the presentation of information, on an immediate comprehension test, and on the evolution of acquired knowledge, through a comparison between a pre-test and a delayed post-test.

For immediate comprehension, we have shown a positive effect of animations when compared to the static version and an effect of the signaling cues for the explanations concerning the system. These signals, guiding attention towards what must be watched on the animation, seems to improve the ability of the learner to explain the technical device suggesting that a deeper processing takes place. In this immediate comprehension test, we did not find any effect of the presentation rhythm. All the expected interactions were not found: notably between the illustration formats and the signaling techniques to direct learner attention, and between the illustration formats and the control over the presentation of the information. But, a positive effect of signaling is significantly present when the learner controls the presentation.

On the longer term, the study of the gains between the pre-test and the post-test, show that these effects are still present, even stronger, which indicated that they are not ephemeral products of way of encoding of the delivered information. The effect of animations lasts and seems to be a positive consequence of the learner-control over the presentation of information. The expected interactions between the different experimental conditions are partly verified. The positive effect of animations especially appears in the self-controlled modality. Signaling cues are only efficient in the self-controlled modality. The learner-control therefore appears as an important condition to process animated multi-modal information, and even much more than a slow rhythm of presentation. These results obtained with young students are congruent with those obtained with adults by Mayer and Chandler (2001) on the phenomenon of lightning, and by Shwan and Riempp (2004) about videotaped tying nautical knots procedures.

The self-controlled pace of presentation, specific to each learner, seems to be the most efficient rhythm on the long term. Self-control of the material is closer of the participant's pace at integrating information and it could make the learner more active in a task which rhythm he regulates himself. The controlled rhythm seems especially more adequate when the processing demand of the task and the cognitive load increase. Let's note that the slow condition produces the weakest gains.

We have also showed a prior knowledge effect on the gains between the pre-test and the post-test. The students with the lowest prior knowledge benefit the most from the animations and from the self-controlled rhythm. The different modalities of presentation do not have any effect for the participants having high prior knowledge. These results seem to agree with our predictions, and with the approach presented in the introduction. The questions asked in the immediate comprehension test and in the pre and post-tests mainly concern the direction of rotation and the speed of the gearing system. Answering accurately these questions requires the participant to build a dynamic representation of the wheels of the gearing system. One result appears as more important: the benefits of the animated condition are the more significant in the self-paced condition. It is also the case for the gains linked to signaling cues. Thus, the difficulty to apprehend a continuous movement, recently underlined by Tversky, Bauer-Morrison, and Bétrancourt (2002), by Tassini and Bétrancourt (2003), by Lowe (1999, 2004a), and by Schwan and Riempp (2004) could be decreased in a self-paced condition, because processing the animations more efficiently would then be possible. Cognitive processing could again be facilitated by the presence of specific attentional signals. However, the learner needs to be able to interact efficiently with a controllable animation. This interaction could be a difficult task for complex domains in which the mastering of abstract underlying concepts is required, like Lowe, 2004b, shows in the case of animated weather maps in the domain of meteorology.

Learners with the lowest prior knowledge are those who benefited most from the cognitive aids introduced. The students with higher prior knowledge could have been able, even before the lesson, to generate dynamic internal representations of gearing systems. For them, an animated illustration brings very little extra information that the static illustration.

The exploratory results reported on reading "strategies" of multimedia documents show an effect of the different conditions of presentation on the nature of the behavioral activity of the participants. The animated illustrations, the signaling technique, especially in the self-paced presentation rhythm seem to influence the production of active strategies of information research, divided parsimoniously between the different sources. These strategies imply that the time needed to process the information increases, which is congruent with the fact that the richest versions (dynamic with signaling cues for example) include more information. Varying the modality of presentation of the illustration-text information thus produces different levels of investment into the task. Controllable animated conditions that support active learning, with specific signals that guide attention, seem to generate a more intense activity ("shifting between the media"). Does this "added" activity always perform a better comprehension? This is not always sure. Wright, Milroy, and Lickorish (1999) have shown no effect of this kind of activity for the comprehension of procedural texts. But in the Shwan & Riempp (2004) experiment on nautical knots tying the learners use with a very high level of efficiency the interactivity possibilities of the controllable version. On this topic, developing the still rare "on-line" research with the analysis of the eye movements of the participants (Hegarty & Just, 1993; Narayannan & Hegarty, 2000; Blackwell, Jansen, & Marriott, 2000; Tabbers, Paas, Martens, & Van Merriënboer, 2002; Tabbers, 2003; Baccino, 2004) could provide evidence to be very profitable for the study of the cognitive processing strategies for multimedia documents.

Notes

1 Given the ergonomic goal of this work, we drew our inspiration from the "Encarta" encyclopedia, which unfolding process we completely rebuilt. The lesson was carried out with Director 7 software (Macromedia).

2 The student is asked to read out loud a series of sentences (each series includes 2, 3, 4 or 5 sentences, of 4 to 6 words), and to repeat the last word of each sentences to memorize it. Then, the participant must at the same time read the sentences and keep active in memory the last word of each sentence. The words used are simple are known from young pupils (examples: 1 – He's a good detective – The doors are open – I like stories – The ball is going too fast – I like your tie very much. 2 – The rabbit has big teeth – The plant has pretty flowers – You have a polka-dot shirt – The earth revolves around the sun).

3 In the first subtest, a letter is presented to the student who must then keep this item in memory and determine, among 5 identical letters that do not have the same position in space, the letter that represents the first letter presented after a rotation, the other letters are identical but presented as in a mirror. After the letter items, objects and then figures are presented. In the second subtest, the students' look at a drawing of bricks stacked in a specific way, and must imagine this configuration from behind. Then, he must choose, among 5 stacks of bricks, the right representation when seen from behind. The third subtest includes a series of square patterns where oblique lines are drawn. The child looks at this figure and memorizes it, and must recognize it among 5 other figures. Finally, the fourth subtest is a complex figure reproduction task.

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Cet article porte sur la compréhension d'un document technique multimédia concernant le fonctionnement des engrenages pour de jeunes élèves. Nous étudions le rôle de trois facteurs: le format de présentation de l'illustration (dynamique ou statique) les signaux d'orientation attentionnelle (présence ou absence de guidages) et le contrôle par l'élève sur le déroulement de la leçon à travers trois rythmes de présentation (rapide, lent et auto-contrôlé). Une procédure expérimentale en quatre phases est conduite auprès d'une population de 123 élèves de primaire: pré-test, consultation individuelle de la leçon, épreuve de compréhension immédiate, post-test différé. Le pré-test comporte l'évaluation des connaissances préalables, des épreuves de mémoire de travail (verbales et spatiales) et une épreuve de lecture. Les résultats montrent un effet des animations, des guidages attentionnels ainsi que du rythme de présentation en compréhension immédiate et au post-test différé. En compréhension immédiate, ces effets sont différenciés selon le type de question (rappel, transfert, explications). Ils se maintiennent au post-test dans la condition d'auto-contrôle et surtout pour les élèves ayant de faibles connaissances préalables. La variable rythme de présentation à un effet au post-test différé. Le dispositif d'observation du comportement de l'élève permet d'explorer les stratégies de traitement des différents médias.

Key words: Animation, Comprehension, Learner-control, Multimedia learning, Signaling.

Received: September 2003

Revision received: January 2004

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Current theme of research:

Cognitive psychology of professional training, comprehension and production of multimedia technical documents, animation cognitive processing, multimedia learning, simulator training, eye tracking.

Most relevant publications in the field of Psychology of Education:

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Current theme of research:

Text and illustration comprehension in education.