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Static and animated presentations in learning dynamic mechanical systems

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Abstract

In two experiments, we investigated how learners comprehend the functioning of a three-pulley system from a presentation on a computer screen. In the first experiment ($N = 62$) we tested the effect of static vs. animated presentations on comprehension. In the second experiment ($N = 45$), we tested the effect of user-control of an animated presentation on comprehension. In both experiments the participants were university students. Comprehension was measured with a test including three comprehension indicators. The first experiment indicated that an animation as well as integrated sequential static frames enhanced comprehension. The second experiment showed that a controllable animation did not have a powerful effect on comprehension, except for learners with low spatial and mechanical reasoning abilities.

Keywords: Static pictures; Animation; User-control; Spatial ability; Comprehension; Mechanical reasoning ability; Expertise reversal effect

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1. Introduction

In spite of the recent explosion of animated websites in education, the cognitive benefits of animated illustrations in the understanding of dynamic mechanical systems included in technical or scientific documents remain disputable (Bétrancourt & Tversky, 2000; Tversky, Bauer-Morrison, & Bétrancourt, 2002). While a small number of studies show positive effects of animation in understanding complex systems (Hidrio & Jamet, 2002; Mayer, 2001; Rieber, 1990, 1991; Rieber, Tzeng, & Tribble, 2004) other studies show little or no effect (Harrison, 1995; Kinze, Sherwood, & Loofbourrow, 1989; Lazarowitz & Huppert, 1993; Mayer, Hegarty, Mayer, & Campbell, 2005; Palmiter & Elkerton, 1993; Pane, Corbett, & John, 1996) or even a negative effect (Lowe, 1999, 2004; Schnotz & Grzondiel, 1999). This study aimed at investigating which types of static and animated illustrations presented on a screen can enhance the learning of a dynamic mechanical system.

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1.1. *Efficiency of animations*

One of the reasons why animations fail to improve comprehension of dynamic systems is related to their frequent violation of the ‘‘apprehension principle’’ defined by Tversky et al. (2002): ‘‘the structure and content of the external presentation should be readily and accurately perceived and comprehended’’ (p. 256; see also Bétrancourt, 2005). An animation conveys changes in the depicted phenomenon as well as movement over time. However, perceptual and cognitive processing limitations constrain the comprehension of a changing visual situation (Ayres & Paas, 2007; Mousavi, Low, & Sweller, 1995). Moreover, changes may regard different elements of a dynamic mechanical system while the movement of the elements is simultaneous. Furthermore, learners often have to share attentional resources between text and animation. Thus, animations are often very hard to perceive and to process (Bétrancourt, Bauer-Morrison, & Tversky, 2001) and pose strong perceptual, conceptual, and working memory demands (Ayres & Paas, 2007; Bétrancourt & Tversky, 2000).

One reason why learners do not benefit from animations is probably the insufficient ways in which spatial and temporal changes are communicated. More ‘‘apprehendable’’ external displays accompanied by text and illustrations could improve the building of accurate mental representations of dynamic technical systems. Within this framework, we conducted two experimental studies in order to investigate if two kinds of cognitive aids, based on static and animated presentations accompanied with text, improve comprehension of a dynamic mechanical system. The first cognitive aid was based on a static presentation that conveyed the key steps of the functioning of a dynamic mechanical system. The second was based on interactive processes between the animation and the learner, and regarded the efficiency of user-control of the course of the animation.

1.2. *Illustration of dynamic information*

One possible way to produce a more ‘‘apprehendable’’ representation of a dynamic mechanical system could be to design, instead of an animation, multiple static frames which discretely, but precisely, depict the key steps of a dynamic process. In this case, the static design is employed in order to support the learner’s cognitive simulation of the dynamic process. Previous research has shown that a sequential external presentation of a dynamic process can bring more benefits than animation (or as much as an animation) in enhancing mental representation (Hegarty, 1992, 2004; Hegarty, Kriz, & Cate, 2003; Mayer et al., 2005; Paas, Van Gerven, & Wouters, 2007; Zacks & Tversky, 2003). However, other recent studies have shown that a continuous animated presentation outperforms a static presentation (Bétrancourt, Dillenbourg, & Clavien, in press; Catrambone & Fleming Seay, 2002; Thompson & Riding, 1990). To explain the contradictory findings one could pose the question if it is the nature of the elements of a dynamic mechanical system that makes the difference on how they are presented and, consequently, learned.

Hegarty et al. (2003), using the toilet cistern system, showed that multiple static illustrations of the main phases of the functioning of the system, which showed how the device works, improved mental representation and increased comprehension compared to single animated or single illustrations. In a study concerning three-pulley systems (Hegarty, 1992), the participants had to perform a task regarding the kinematics of the system based on a static picture. The results indicated that to infer the movement of the lower pulley (at the end of the causal chain) the participants inspected the upper pulleys (at the beginning of the causal chain). They inferred the components’ motion ‘‘beginning by imagining the rope being pulled and working through the causal chain of events in the motion of the system’’ (Hegarty, 2004, p. 282). This piecemeal strategy seems consistent with a discrete representation of the local events. Mayer et al. (2005) compared the effectiveness of presenting different types of content via sequences of paper-based static pictures (accompanied by text) with presenting the same content via computer-based narrated animations. No advantages were found for animations across the four content-types examined (lightning storms, toilet cistern, ocean waves, and car brakes).

However, inferring motion transitions between discrete static pictures could be difficult. Thompson and Riding (1990), using a lesson about the Pythagorean Theorem, showed that the performance of participants who worked with a continuous animation was better than that of two other groups who learned the steps of geometrical transformations using a discrete multiple presentation of static graphics on paper or using a single static graphic. In learning computer algorithms, Catrambone and Fleming Seay (2002) showed that an animation was a better aid than a discrete static graphic presentation taken from an animation. Bétrancourt et al. (in press) found that a continuous animated presentation of lightning storms outperformed a discrete static-frame presentation in a retention and transfer test.

Participants in the continuous animated presentation spent more study time than those in the discrete static-frame presentation, thus suggesting that a series of static frames did not always lead to strong inference activity.

The contradictory results observed when comparing continuous animation and sequential static frames could be partly due to micro-step granularity and to the conditions under which the sequences of static frames were presented. Concerning granularity, Tversky et al. (2002) noted that ‘‘many of the static graphics portray only the coarse units’’ of a process or of an object ‘‘whereas the animations portray both the coarse and the fine segment’’ (p. 252). However, multiple graphics should depict more fine-grained segmentation, without adding too much information, to avoid cognitive overload. The presentation of sequential static frames is a crucial point because inferential activity could depend on it.

1.3. Static vs. animated presentation

In previous research the conditions of static sequential presentation were not always specified. Static frames can be presented according to two conditions at least. In the first case each static frame appears independently of the others: the first frame disappears when the second appears, and so forth. Under such circumstances, the new information may override the old information in working memory. Such a sequential independent-static-frame presentation may also interfere with the perception of continuity of the movements and also increase cognitive demands because the learner has to maintain the first frame in working memory while the second is processed (Ayres & Paas, 2007; Paas et al., 2007). Moreover, it can be assumed that sequential independent-static-frame presentation could interfere with inferential activity by increasing extraneous cognitive load (Paas et al., 2007).

In the second case, integrated sequential static frames are presented side by side on the same screen. The entire segmented process is available simultaneously for the learner. This presentation can support the building of a precise dynamic mental representation. Each step of the process is visually accessible on the same screen, allowing the learner to mentally create and maintain continuity in the perception of the process. Moreover, direct visual comparisons between the different steps are possible, enhancing germane load (Ayres & Paas, 2007). Such comparisons may generate inferences about steps of finer granularity between the main coarse steps. It can be assumed, then, that this type of integrated sequential presentation of static frames is particularly effective for the processing of information involving elaboration of the mental representation of dynamic mechanical systems (Bétrancourt & Tversky, 2000; Tversky et al., 2002).

1.4. User-control of animation

Another way to present more apprehendable animations, recently explored by a number of researchers (Boucheix, 2008; Boucheix & Guignard, 2005; Kriz & Hegarty, 2004; Lowe, 2004; Mayer & Chandler, 2001; Price & Rogers, 2004; Schwan & Riempp, 2004; Tassini & Bétrancourt, 2003), regards user-control on the animation's course. Interactive displays provide the opportunity to stop, rewind, and restart, to slow down, or to change directions. Interactivity, from the point of view of memory demands, should lead to less cognitive load and should improve comprehension. User-control also gives the learner the opportunity to replay a part, thus shaping the display. A learner can adapt the display speed to his/her own rate of cognitive processing. A first basic level of user-control regarding the rate of presentation of multimedia slides has been studied by Boucheix and Guignard (2005) and Mayer and Chandler (2001). These studies showed the advantage of this level of user-control.

More sophisticated procedures in user-control of animation were tested by Schwan and Riempp (2004). They tested two levels of interactivity. Specifically, students learned to tie four nautical knots of varying complexity by watching either controllable or non-controllable video presentations. In the controllable presentation, participants could stop, reverse, replay and modify the video's speed. In the non-controllable presentation the speed and duration of the video were fixed and participants could only restart the animation from the beginning. The results showed that the controllable presentation led to a strong reduction in the cognitive load related to the processing of the task.

However, allowing full control of an animation is not necessarily always effective. Novices may not be able to use the animation's interactivity features effectively when faced with complex tasks or systems – the same regards, for example children (Boucheix, 2008). In the field of meteorological maps, Lowe (2004) found that novices who worked with user-controlled weather maps, animation was ineffective because they tended to focus upon features that were perceptually salient rather than thematically relevant (see also Bogacz & Trafton, 2005). Consistent with these results, Kriz and Hegarty (2004, 2007) found that students with low prior relevant knowledge were unable to build an adequate model of how a novel device works using controllable animation. In studies of undergraduate students' learning about brain synapse mechanisms, Bétrancourt et al. compared non-controllable, partly-controllable and fully-controllable versions of animated presentation (Bétrancourt & Réalini, 2005; Tassini & Bétrancourt, 2003). They found that user-control of the animation did not produce superior comprehension; the best results were obtained with the non-controllable version.

The above contradictory results have been found with widely differing contents: from procedures which presuppose imitation to predicting weather which presupposes a high level of abstract prior knowledge. Learning to tie a knot is facilitated if the animated presentation can be stopped, restarted, and slowed down, because the skill to be acquired can be divided into short sequences that need different amounts of time to perform. In this case, a non-stop animation would involve memorizing of a long sequence of movements without any opportunity to stop or manipulate the animated presentation. User-control of an animation implies that the learner is able to efficiently manage his/her own informational needs (Boucheix, 2008; Lowe, 2005). However, this is not easy if the task is complex or abstract. On the other hand, in the great majority of the above mentioned studies, only two conditions were compared: non-controllable with fully controllable. Levels of user-control that are halfway between complete user-control and complete system-control have been neglected. The degree of user-control that learners are given over the animated system could affect learner performance. In the case of a high level of user-control, learners determine the course of the animation and how the displayed content is segmented into units. If the material is segmented inappropriately, then this could lead to flaws in subsequent processing. The potential for such difficulties increases along with the complexity of the subject-matter involved and is also likely to be greater when the learner lacks sufficient prior knowledge. However, giving the learner too little user-control may also be problematic due to perceptual and memory difficulties that may occur.

Some intermediate level of user-control may provide a better match of the learner's processing ability with the processing demands posed by the animation. For example, it is possible that some features of a dynamic process are best understood if the animation is controlled by the learner whilst others if the animation is fixed by the presentation system. One possibility could be that the presentation of the main steps of the dynamic process is system-driven, while the control of the animation's course within these main fixed steps is learner-driven. Findings from several recent empirical studies tend to support the use of such an approach. In Schwan and Riempp's (2004) study on knot tying, participants used the pause function extensively to temporarily stop the animation. It seemed that they needed to halt the continuous animation in order to understand crucial steps in the procedure. Studies involving animated meteorological information (Bogacz & Trafton, 2005; Lowe, 2003, 2004) found that static frames were sometimes chosen in preference to the display of a continuous flow of dynamic information. It may therefore be inappropriate to give low prior-knowledge learners complete control over animation. Rather, it is possible that a carefully chosen blend of controllable and fixed features could provide an optimal sharing of control between the learner and the system. For example, novice learners may benefit from having fixed the parts of the animation involving natural functional constraints (e.g., the main functional steps and their boundaries, the key states of a continuous movement, and the overall movement directions) while being given control over the animation-specific features or the particular course within the fixed parts.

1.5. Spatial ability

The ability to infer the behaviour of a mechanical system from static diagrams refers to mental animation activity (Hegarty, 1992; Hegarty & Waller, 2005). Previous research indicated that mental animation is highly correlated with spatial and visual abilities (Cornoldi & Vecchi, 2003; Hegarty & Kozhevnikov, 1999; Hegarty & Sims, 1994; Hegarty & Steinhoff, 1997; Hegarty & Waller, 2005; Sims & Hegarty, 1997). In these studies, differences in performance between high and low spatial ability individuals were greater for items in which more mechanical components had to be mentally animated. Low spatial ability individuals made more errors than high spatial ability ones (Hegarty & Waller, 2005). High spatial ability participants also outperformed their low spatial ability counterparts in understanding mechanical systems from text and static pictures (Hegarty, 1992; Hegarty & Just, 1993). Are, then, multimedia presentations, and particularly animations, more effective for low spatial ability participants? Viewing animations might be more effective than static diagrams for low spatial ability individuals because these individuals have less ability to mentally animate static diagrams. An animation might function "as a type of cognitive prosthetic" (Hegarty, 2005, p. 457) for those with low spatial abilities.

However, recent literature about the effect of spatial ability on multimedia showed contradictory results (Hegarty, 2004). In some cases (Hegarty, 2004; Hegarty et al., 2003; Narayanan & Hegarty, 2002) there was no interaction between spatial ability and format of diagrams (static vs. animated). In some other cases high spatial ability individuals were better able to perceive and learn from animation (Garg, Norman, & Sperotable, 2001; Garg, Norman, Spero, & Maheshwari, 1999; Isaak & Just, 1995; Mayer & Sims, 1994). In other cases there was an interaction between the controllability of the animation presented to the participant (self-paced or system fixed) and spatial ability. For example, Boucheix and Guignard (2005) showed, with children participants, that the performance gains between a pretest and a posttest concerning the comprehension of gear functioning were higher for low spatial than for high spatial ability children in the self-paced condition of presentation of the animation compared to the fixed condition of presentation. So it might be expected that a segmented format of presentation enlightening the main micro-steps of the dynamic processes would particularly help low spatial ability learners to realize relevant inferential activities and mental animation. Such segmented presentation has also to maintain perceptual continuity between the depicted micro-steps. Integrated sequential static frames presented side by side on the same screen could reach these goals. User-controllable animations, and particularly partial controllability, as we defined it above, could also benefit the low spatial ability learners when understanding a mechanical system.

1.6. Hypotheses

The predictions deriving from the above theoretical overview as regards the factors affecting multimedia learning were tested in two experiments. Experiment 1 was carried out in order to compare the effect of four different presentation formats on the comprehension of a technical document concerning the functioning of a three-pulley mechanical system (Hegarty & Just, 1993) on a computer screen: a single static frame, two static multiple-frame presentations (one integrated and one independent sequential), and a full animation presentation. The prediction was that presentation of integrated sequential static frames, which describe a dynamic process and facilitate elaboration of the mental representation of movement, should lead to similar performance on a comprehension test as an animated presentation of the same process, and higher performance than the presentation of sequential independent static frames or a single static frame (Hypothesis 1). The benefit of animation and integrated static frames was expected mainly in deep comprehension, that is, in the functional mental model (‘‘the runnable model’’, Mayer, 2001, 2005) of the mechanical system. As explained above, these two formats should maintain the perceptual continuity of the dynamics of the technical process and enhance inferential activities. Moreover, the benefits of integrated sequential static frames should be particularly significant for learners with low spatial and mechanical reasoning abilities, because the presentation properties would facilitate the drawing of relevant inferences (Hypothesis 2).

In Experiment 2 we studied how different levels of user-control affect comprehension of the three-pulley system (as in Experiment 1) presented on a computer screen (Hegarty & Just, 1993). The three-pulley system can be conceived as representing an intermediate level of complexity between learning a skill (such as tying simple knots) and a task with abstract content (such as using meteorological maps). We tested three levels of user-control. A non-controllable condition was compared to two controllable conditions: one allowing full control, the other only partial control. In the partly-controllable condition, the animation was divided into five main fixed micro-steps. Each micro-step was fully controllable. Such fixed shaping of the animation of a dynamic mechanical system could be related, to some extent, to Mayer’s segmentation principle for narrated animation (Mayer, 2001, see also Bétrancourt, 2005). However, in the design of our device, the features of controllability affected the animated presentation of the mechanical system itself and not the physical system of control, e.g., via the mouse (Bétrancourt & Réalini, 2005; Tassini & Bétrancourt, 2003). In the fully-controllable presentation, participants could control the pace and the speed of the animation as they wanted. The non-controllable presentation consisted of an animated illustration of the three-pulley system. After the animation started the learner could not stop the course of the system until the end.

Following the above rationale we expected higher comprehension of the functioning of the mechanical system in the two controllable presentations as compared to the non-controllable, as regards mainly the functional mental model (‘‘the runnable model’’, Mayer, 2001, 2005) of the mechanical system (Hypothesis 3).

Moreover, the controllable presentation, and particularly the partly-controllable one, should benefit low spatial and mechanical reasoning ability participants (Hypothesis 4).

2. Experiment 1

The aim of Experiment 1 was to study the effect of the presentation format on the comprehension of the functioning of the mechanical three-pulley system presented on a computer screen. The four experimental conditions were the following: a single static frame (Condition 1), five integrated sequential static frames (Condition 2), five sequential independent static frames (Condition 3), and an animation (Condition 4).

2.1. Method

2.1.1. Participants

Participants were 62 undergraduate students (55 females and 7 males[1]) from the University of Burgundy who attended a compulsory Psychology course that gave experiment credit. Their mean age was 20.7 years (SD = 5.12). There were 16, 14, 17, and 15 participants for Conditions 1, 2, 3, and 4, respectively. Before the experiment, participants were asked about their possible task-specific prior knowledge. None of the participants selected for the experiment had specific prior knowledge about mechanical pulley systems. Moreover, the mechanical pulley system used in the experiment is not a school topic in secondary school (11–18 years old) and definitely not in the university for psychology students. It is briefly touched upon in primary school (7–10 years old) and only at a very low level.

2.1.2. Material

The explanatory text (in French) was composed of eight paragraphs in which the configuration of the three-pulley system and its functioning was explained (see Fig. 1). The level of interactivity of the four presentations was identical: the learner began the session by clicking for the text to appear and then he/she had to click again so that the illustrations show up on the screen. In the animated presentation, the three-pulley system appeared when the participant clicked on any point of the illustration area. The single-static-frame presentation consisted of a single static frame which depicted the three-pulley system when the rope was at the initial point (see Fig. 1).

The integrated-sequential-static-frame presentation was composed of five frames which depicted the five main steps of the functioning of the three-pulley system presented on the same screen (see Fig. 2). The sequential-independent-static-frame version consisted of the same five frames, as in the previous version, but the five frames were presented successively, one after the other; when the participants clicked their mouse within the illustration area a new frame appeared and the previous one disappeared. The animated presentation delivered a dynamic simulation of the three-pulley system.

2.1.3. Comprehension measures and scoring procedure

After studying the document on a computer, participants were asked recall and comprehension questions in three sets, which were based on Hegarty's model (Hegarty, 1992, 2004; Narayanan & Hegarty, 1998, 2002). We defined three comprehension indicators, namely configuration, local kinematics, and functional mental model. The set of questions were the following.

A set of 12 questions tested recall of information related to the configuration of the three-pulley system; for example, "Which components touch the middle pulley?" Each correct answer was given one point, and the maximum score was 12 points. A half point penalty was taken away from the total score for each incorrect answer; for example, for the question "Which components touch the lower rope?" the answers "lower pulley" and "middle pulley" were credited one point, while for the answer "the upper pulley" a half point penalty was taken away from the question score. Then, each participant's score was transformed into a percentage of the maximum score.

A second set of 10 questions (composed of 29 sub-questions) concerned the comprehension of the local kinematics of the system, that is, direction, rotation, and speed of each pulley; for example, a question was "Does the middle pulley move when the top rope is pulled?" The sub-questions were "If the middle pulley moves, in which direction does it go? Clockwise, counter-clockwise?" Each correct answer was given one point, and the maximum score was 29 points. A half point penalty was taken away from the total score for each incorrect answer; for example, for the question "What does the upper pulley do?" The answer "it moves" was credited one point and the sub-answer "clockwise" was credited one point; but for the answer "it stay at the same place" or the answer "it does not move" a half point penalty was taken away from the question score. Then, each participant's score was transformed into a percentage of the maximum score.

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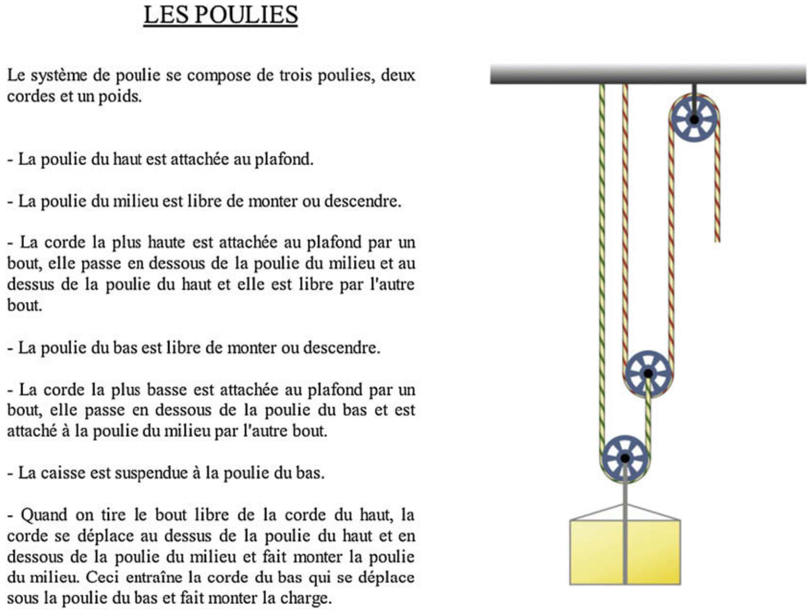
[1] This composition is ordinary for the Psychology Departments in France.



LES POULIES

Le système de poulie se compose de trois poulies, deux cordes et un poids.

- La poulie du haut est attachée au plafond.

- La poulie du milieu est libre de monter ou descendre.

- La corde la plus haute est attachée au plafond par un bout, elle passe en dessous de la poulie du milieu et au dessus de la poulie du haut et elle est libre par l'autre bout.

- La poulie du bas est libre de monter ou descendre.

- La corde la plus basse est attachée au plafond par un bout, elle passe en dessous de la poulie du bas et est attaché à la poulie du milieu par l'autre bout.

- La caisse est suspendue à la poulie du bas.

- Quand on tire le bout libre de la corde du haut, la corde se déplace au dessus de la poulie du haut et en dessous de la poulie du milieu et fait monter la poulie du milieu. Ceci entraîne la corde du bas qui se déplace sous la poulie du bas et fait monter la charge.

Fig. 1. Explanatory text and static-frame presentation.

A sole open question measured comprehension of the complete functional mental model (‘‘runnable’’ model) of the three-pulley system. It required integration of the components and local kinematics of the three-pulley system. The question was: ‘‘Describe as precisely as possible what happens to all of the system’s elements when a person pulls the top rope.’’ A scoring criteria grid with 10 possible correct answers was used to rate the answers of each participant: every correct movement (presence of movement, direction, relative speed) of each component (pulleys, ropes, ceiling, and load) was credited with one point; for example the answer ‘‘When a person pulls the top rope the rope moves over the upper pulley’’ or ‘‘The middle pulley turns over and counter-clockwise’’ was credited with one point. The maximum score was 10 points. A half point penalty was taken away from the total score for each incorrect answer. Then, each participant’s score was transformed into a percentage. Participants’ answers were evaluated by two independent raters with an interrater agreement of 94%.

2.1.4. Spatial and mechanical reasoning abilities

The French version of the Differential Aptitude Test (DAT; Bennett, Seashore, & Wesman, 2002) was used to measure spatial and mechanical reasoning abilities. The DAT (Booklets 4 and 5) was composed of two subtests: spatial relations and mechanical reasoning. The Spatial Relations subtest measured mental rotation ability for figures. The Mechanical Reasoning subtest measured the understanding of basic mechanical principles (gearwheel, lever and movement processing). These abilities, namely mental rotation and basic mechanical reasoning, are presumably used to understand the three-pulley system presented in the experiments. The aim of measuring them was to differentiate participants with high and low abilities. As a result of the significant correlation, $r(61) = 0.56$, $p < 0.01$, between mental rotation and mechanical reasoning abilities in our sample we averaged the mechanical reasoning ability score with the spatial ability score for all participants. Based on the single spatial and mechanical reasoning score of each participant, we calculated the median. The median defined the boundary between participants with high and low mechanical reasoning and spatial abilities. The median was 54% correct answers.[2] There were 33 high- ($M = 64.70$, SD = 8.10), and 29 low-ability participants ($M = 45.80$, SD = 6.30). The difference between the high- and low-ability

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[2] Note that with a 54% median score, the spatial and mechanical reasoning abilities of the participants of our study were situated within the sixth level out of 11 according to the French reference normalization table (Bennett et al., 2002, Normalization Table, p. 74). It should be also noted that the representative sample used for the French reference normalization of the DAT test (French adults, Superior to Advanced Level, 50% females and 50% males; Bennett et al., 2002, p. 46) scored an average of 42.83% for females and 55.33% for males for spatial relations and mechanical reasoning combined. Therefore, the spatial and mechanical reasoning abilities of our sample, mainly composed of females, appeared to be much closer to the male rather than to female population of the French normalization tables.

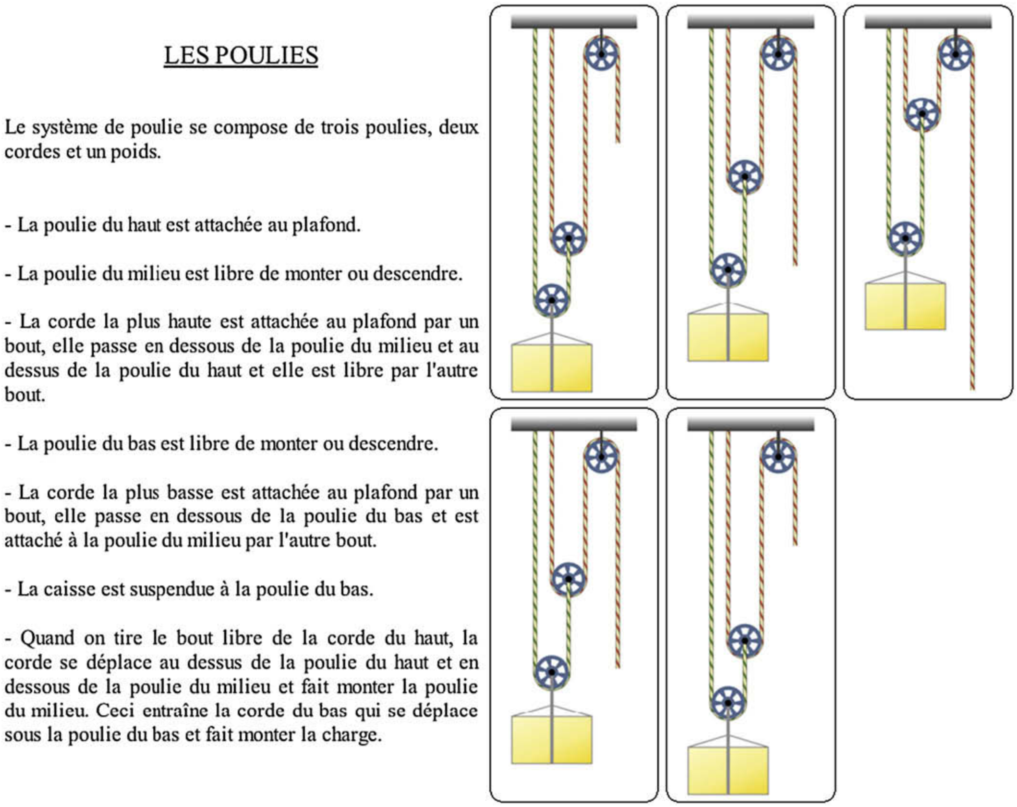

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Fig. 2. Explanatory text and integrated-sequential-static-frame presentation.

participants, as revealed by a 4(condition) × 2(ability) ANOVA, was significant, $F(1, 54) = 104.76$, $p < 0.001$, Cohen's $d = 2.58$, but the difference between the four conditions was not significant, $F(3, 54) = 1.6$, ns.

Post hoc tests indicated a significant difference between the high- and low-ability groups in each of the four conditions ($p < 0.01$, Student–Newman–Keuls test). Furthermore, post hoc tests indicated no significant difference between either the high-ability groups ($p > 0.05$, Student–Newman–Keuls test) or the low-ability groups ($p > 0.05$, Newman–Keuls test) across the four conditions.

2.1.5. Procedure

The overall testing involved three stages. At first, the participants' mechanical reasoning and spatial abilities were group tested. In the second stage the participants were presented with the explanatory text and illustration of the three-pulley system on a computer screen. Their task was to understand how the three-pulley system worked as precisely as possible. The participants were given unlimited time to study the explanatory text and illustration. However, they had to use the animation or process the static frames at least three times.

In the third stage participants answered the comprehension questions in a booklet.

2.2. Results

2.2.1. Comprehension performance

Table 1 presents the performance scores on the three comprehension indicators (configuration, local kinematics, and functional mental model) in the four conditions.

A MANCOVA including condition as between-subjects factor and ability (DAT mean score) as covariate with the three comprehension scores as dependent variables was performed. The multivariate test was significant, Pillai's = 0.32, $F(2, 56) = 13.37$, $p < 0.001$, partial $\eta^2 = 0.18$. There was a main effect of spatial and mechanical reasoning abilities, $F(1, 57) = 8.02$, $p = 0.006$; partial $\eta^2 = 0.12$, but no main effect of condition, $F(3, 57) = 1.23$,

Table 1
Mean performance (and SD) on the three comprehension indicators as a function of condition and ability

	Condition				
	1 ($n = 16$)	2 ($n = 14$)	3 ($n = 17$)	4 ($n = 15$)	Total ($N = 62$)
Configuration					
High ability ($n = 33$)	88.43 (6.51)	86.98 (8.75)	90.27 (15.45)	83.33 (17.17)	87.50 (12.19)
Low ability ($n = 29$)	79.76 (10.60)	88.89 (13.35)	88.02 (9.56)	83.85 (10.78)	85.05 (10.99)
Total ($N = 62$)	84.64 (9.34)	87.80 (10.52)	89.21 (12.68)	83.61 (13.6)	86.35 (11.61)
Local kinematics					
High ability ($n = 33$)	70.06 (13.73)	75.35 (13.15)	79.38 (18.00)	67.46 (19.69)	73.33 (16.13)
Low ability ($n = 29$)	70.56 (19.51)	69.72 (22.01)	70.90 (15.40)	60.97 (20.17)	67.83 (18.65)
Total ($N = 62$)	70.28 (15.90)	72.94 (16.96)	75.39 (16.87)	64.00 (19.51)	70.76 (17.43)
Functional mental model					
High ability ($n = 33$)	52.77 (12.15)	64.06 (21.59)	50.00 (6.25)	58.92 (18.70)	56.06 (15.66)
Low ability ($n = 29$)	30.36 (17.47)	58.33 (12.90)	31.25 (29.88)	46.87 (21.9)	40.94 (23.8)
Total ($N = 62$)	42.97 (18.24)	61.60 (17.99)	41.17 (22.43)	52.50 (20.7)	49.00 (21.14)

Condition 1: single static frame; Condition 2: integrated sequential static frames; Condition 3: sequential independent static frames; Condition 4: animation. High ability: participants with high spatial and mechanical reasoning abilities; low ability: participants with low spatial and mechanical reasoning abilities.

$p = 0.30$. As expected, a significant interaction between the three comprehension measures and condition was found, $F(6, 114) = 3.02$, $p = 0.009$, partial $\eta^2 = 0.14$, revealing different condition effects depending on the comprehension measure.

The ANCOVA in the case of configuration, with condition as between-subjects factor and spatial and mechanical reasoning abilities as covariate, showed that the main effect of condition was not significant, $F(3, 57) < 1$, ns. Also, there was no effect of ability, $F(1, 57) = 2.54$, $p = 0.11$. The interaction of ability with condition was also nonsignificant, $F(3, 58) = 0.90$, ns.

A similar pattern of results was found in the case of local kinematics. No main effect of condition was found, $F(3, 57) = 1.15$, ns. Also, there was no effect of ability, $F(1, 57) = 1.23$, ns. Finally, the interaction of condition with ability was also nonsignificant, $F(3, 58) = 1.33$, $p = 0.27$, ns.

A different pattern was observed with regard to the functional mental model. The ANCOVA with condition as between-subjects factor and spatial and mechanical reasoning abilities as covariate showed a main effect of condition, $F(3, 57) = 3.62$, $p = 0.018$, partial $\eta^2 = 0.16$. The planned contrasts of the four conditions showed that the integrated-sequential-static-frame condition had higher score than the single-static-frame condition and this difference was significant, $F(1, 57) = 5.38$, $p = 0.023$, Cohen's $d = 1.01$. The difference between the animation condition and the single-static-frame condition was nonsignificant, $F(1, 57) = 1.34$, ns. The integrated-sequential-static-frame condition outperformed the sequential-independent-static-frame condition, $F(1, 57) = 9.47$, $p = 0.003$, Cohen's $d = 0.99$. There was a marginal difference between the animation condition and the sequential-independent-static-frame condition, $F(1, 57) = 3.6$, $p = 0.06$, Cohen's $d = 0.50$. There were no other significant contrasts.

Also, there was a main effect of spatial and mechanical reasoning abilities, $F(1, 57) = 9.28$, $p = 0.003$, partial $\eta^2 = 14$, that is, the higher the ability the better the performance on the functional mental model. Moreover, the interaction of ability with condition was significant, $F(3, 58) = 3.10$, $p = 0.03$, partial $\eta^2 = 0.14$, revealing that condition had no effect in the case of participants with high ability. On the contrary, for participants with low ability, performance differed as a function of condition, in favour of the integrated-sequential-static-frame condition and of the animation condition.

In summary, performance on the functional mental model indicator was best in the integrated-sequential-static-frame condition and in the animation condition. Moreover, these effects were most pronounced in participants with low spatial and mechanical reasoning abilities.

2.2.2. Study time

Mean study times for each condition are presented in Table 2. To investigate if the differences found in performance on the functional mental model indicator were affected by the time spent studying the explanatory text and the illustrations, an ANCOVA with condition as between-subjects factor, and spatial and mechanical reasoning abilities

Table 2
Mean study time in seconds (and SD) as a function of condition and ability

	Condition				
	1 ($n = 16$)	2 ($n = 14$)	3 ($n = 17$)	4 ($n = 15$)	Total ($N = 62$)
High ability ($n = 33$)	182.4 (59.0)	235.4 (73.9)	206.8 (75.4)	204.3 (91.3)	205.7 (69.3)
Low ability ($n = 29$)	191.0 (64.0)	187.3 (21.7)	216.8 (110.8)	156.2 (64.8)	187.5 (75.7)
Total ($N = 62$)	185.5 (58.5)	213.2 (59.6)	211.5 (90.8)	178.7 (79.3)	197.3 (74.4)

Condition 1: single static frame; Condition 2: integrated sequential static frames; Condition 3: sequential independent static frames; Condition 4: animation. High ability: participants with high spatial and mechanical reasoning abilities; low ability: participants with low spatial and mechanical reasoning abilities.

and study time as covariates was performed. The main effect of condition remained, $F(3, 54) = 3$, $p = 0.04$, partial $\eta^2 = 0.14$, as well as the main effect of ability, $F(1, 54) = 4.88$, $p = 0.03$, partial $\eta^2 = 0.08$. The effect of study time was nonsignificant, $F(1, 54) = 2.06, p = 0.15$. Finally, the interaction of condition with study time was nonsignificant, $F(3, 54) < 1$, ns. These findings indicated that the time spent studying the presentation in the four conditions did not affect the differences found in the comprehension of the functional mental model.

2.3. Conclusion

As expected (Hypothesis 1), presentation of integrated sequential static frames led to similar performance on a comprehension test as an animated presentation of the same process, and higher performance than the presentation of sequential independent static frames or a single static frame. Thus, an animated presentation, in addition to a technical explanatory text, is not the only way to convey information about a dynamic mechanical system. A presentation employing integrated sequential static frames of the functioning of the mechanical three-pulley systems, which conveys the micro-steps of the functioning of the dynamic process, can enhance the construction of a functional mental model. This kind of presentation favours cognitive processing of the micro-steps of the dynamic process, allowing for a certain degree of inference drawing concerning the functioning of the mechanical system. In contrast, a sequence of independent static frames in which the appearance of a frame presupposes the disappearance of the previous one, generates poorer comprehension, equivalent to that of the single static frame. The effect of ‘‘perceptual discontinuity’’, which is probably produced by this kind of presentation, reduces the comprehension of the mechanical system’s continuous functioning. However, it may be the case that this ‘‘perceptual discontinuity’’ depends on how quickly one moves through the frames.

The benefits of integrated sequential static frames, as well as animation, were significant for learners with high and also low spatial and mechanical reasoning abilities. Moreover, the effect of integrated sequential static frames was most pronounced in participants with low spatial and mechanical reasoning abilities as Hypothesis 2 predicted because the properties of this presentation facilitated the drawing of relevant inferences.

3. Experiment 2

In Experiment 1, we showed that animation had better results than single static and sequential independent static frames, but similar to those of integrated sequential static frames as regards the building of a functional mental model of a dynamic mechanical system presented on a computer screen. The question is if user-control of the animation leads the user to improve his/her understanding of the functioning of mechanical systems. To answer this question we conducted Experiment 2. We tested three levels of user-control. Specifically, the participants were presented with an explanatory text and a non-controllable animation (Presentation 1), or a partly-controllable animation (Presentation 2), or a fully-controllable animation (Presentation 3).

3.1. Method

3.1.1. Participants

Participants were 45 (41 females) undergraduate students from the University of Burgundy who attended a compulsory psychology course that gave experiment credit. Their mean age was 20.6 years (SD = 5.78). There were 14, 15, and 16 participants in Presentations 1, 2, and 3, respectively. Before the experiment, participants were asked about their possible task-specific prior knowledge. None of the participants selected for the experiment had prior knowledge about mechanical devices and pulley systems. None of the participants of Experiment 2 participated in Experiment 1.

3.1.2. Material

The same three-pulley system presented in Experiment 1 was used in this experiment.

The non-controllable presentation consisted of an animated illustration of the three-pulley system. The participants started the animation by clicking the mouse within the illustration area. The speed of the three-pulley system simulation was relatively slow (the duration of the whole motion took 8.5 s).

The partly-controllable presentation consisted of five fixed micro-steps. Each micro-step was fully controllable. Participants controlled the presentation with their mouse. One click brought about the next frame. Participants could repeat the animation only when all the micro-steps were completed.

In the fully-controllable presentation, participants could control the animation as they liked—direction (by pulling down or pulling up as they wanted the free end of the top rope) and speed—after they had clicked on the free end of the top rope.

3.1.3. Comprehension measures and scoring procedure

We used the same comprehension questions and scoring procedures as those used in Experiment 1.

3.1.4. Spatial and mechanical reasoning abilities

Participants were given the Differential Aptitude Test (DAT; Bennett et al., 2002) in groups. The mean score of the each participant's performance on the Spatial Relations and the Mechanical Reasoning subtests was used (see Section 2) to calculate the median. The median was 55% correct answers. There were 22 high- ($M = 64.32$, SD $= 8.39$), and 23 low-ability participants ($M = 44.85$, SD $= 6.58$). The difference between the high- and low-ability participants was significant, $F(1, 43) = 75.17$, $p < 0.001$, Cohen's $d = 2.57$, but the difference between the participants in the three presentations was nonsignificant, $F(1, 42) < 1$, ns.

Post hoc tests indicated a significant difference between the high- and low-ability groups in each of the three presentations ($p < 0.01$, Student–Newman–Keuls test). Furthermore, post hoc tests indicated no significant difference between either the high-ability groups ($p > 0.05$, Student–Newman–Keuls test) or the low-ability groups ($p > 0.05$, Newman–Keuls test) across the three presentations.

3.1.5. Procedure

The participants were presented with the three-pulley system individually on a screen. Their task was identical to that of Experiment 1. They were free to study the explanatory text and illustration of the three-pulley system for as long as they wanted. However, participants had to operate the animation at least three times. When they finished studying, as in Experiment 1, participants answered the comprehension questions in a booklet.

3.2. Results

3.2.1. Comprehension performance

Table 3 presents the performance scores on the three comprehension indicators, namely configuration, local kinematics, and functional mental model, in the three presentations.

A MANCOVA including presentation as between-subjects factor and ability (DAT mean scores) as covariate with the three comprehension scores as dependent variables was performed. The multivariate test was nonsignificant, Pillai's $= 0.02$, $F(2, 40) = 0.51$, ns. The results showed no significant main effect of presentation, $F(2, 41) < 1$, ns, and no overall effect of ability, $F(1, 41) < 1$, ns. The interaction between presentation and ability was also nonsignificant, $F(2, 42) = 1.56$, $p = 0.22$.

The univariate tests in the case of configuration showed that performance significantly differed between the three presentations, $F(2, 41) = 9.91$, $p = 0.003$, partial $\eta^2 = 0.19$. Planned comparisons revealed that participants in the partly-controllable presentation outperformed those in the non-controllable presentation, $F(1, 41) = 9.98$, $p = 0.003$, Cohen's $d = 1.09$; participants in the fully-controllable presentation outperformed those in the non-controllable presentation, $F(1, 41) = 4.40$, $p < 0.05$, Cohen's $d = 0.89$; however, performance in the partly-controllable presentation did not differ from that in the fully-controllable presentation, $F(1, 41) = 1.18$, ns. Moreover, the main effect of

Table 3
Mean performance (and SD) on the three comprehension indicators as a function of user-control and ability

	Presentation			
	1 ($n = 14$)	2 ($n = 15$)	3 ($n = 16$)	Total ($N = 45$)
Configuration				
High ability ($n = 22$)	86.30 (4.63)	92.26 (7.39)	93.23 (6.27)	90.71 (6.67)
Low ability ($n = 23$)	77.97 (6.23)	89.06 (9.94)	85.42 (10.45)	84.42 (9.90)
Total ($N = 45$)	82.14 (6.82)	90.56 (8.7)	89.32 (9.25)	87.50 (8.97)
Local kinematics				
High ability ($n = 22$)	80.31 (19.36)	67.46 (16.6)	77.64 (21.87)	75.25 (19.39)
Low ability ($n = 23$)	66.82 (17.43)	76.81 (24.71)	69.03 (13.06)	71.06 (18.72)
Total ($N = 45$)	73.57 (19.03)	72.44 (21.13)	73.33 (17.96)	73.11 (18.95)
Functional mental model				
High ability ($n = 22$)	51.78 (11.24)	42.86 (12.2)	37.50 (20.04)	43.75 (15.78)
Low ability ($n = 23$)	42.85 (22.65)	62.50 (22.16)	57.81 (23.09)	54.89 (23.15)
Total ($N = 45$)	47.32 (17.79)	53.33 (20.3)	47.66 (23.37)	49.44 (20.46)

1: non-controllable presentation; 2: partly-controllable presentation; 3: fully-controllable presentation. High ability: participants with high spatial and mechanical reasoning abilities; low ability: participants with low spatial and mechanical reasoning abilities.

ability was significant, $F(1, 41) = 5.15$, $p = 0.01$, partial $\eta^2 = 0.20$. Participants with high ability had higher configuration scores than those with low ability. A significant interaction of ability with presentation was observed, $F(2, 42) = 4.33$, $p = 0.02$, partial $\eta^2 = 0.17$. High-ability participants performed better than low-ability ones only in the non-controllable presentation.

For the local kinematics, the univariate test showed no significant differences between the three presentations, $F(2, 41) < 1$, ns. The effect of ability was also nonsignificant, $F(2, 42) = 1$, ns. Finally, the interaction of ability with presentation was nonsignificant, $F(2, 39) < 1$, ns.

For the functional mental model also no significant differences were found between the three presentation formats, $F(2, 41) < 1$, ns. The effect of spatial and mechanical reasoning abilities was also nonsignificant, $F(1, 41) = 3.31$, $p = 0.08$. Finally, the interaction of ability with presentation was not significant, $F(2, 42) = 1$, ns.

In summary, the controllability level of the three-pulley system's animated presentation had no effect on all levels of comprehension, although there were some effects as regards the comprehension of the configuration of the three-pulley system.

3.2.2. Time spent studying the presentation

User-control by definition allows more interactivity with the animation than a non-controllable presentation. Therefore, the question is if the lack of significant differences between the three presentations could be due to differences in time studying each presentation. The mean study times for each presentation are presented in Table 4.

To investigate if the differences found in performance on the functional mental model indicator were affected by the time spent studying each presentation, an ANCOVA with presentation as between-subjects factor and ability (DAT mean scores) as covariate was performed, It showed a significant main effect of presentation, $F(2, 39) = 4.01$, $p = 0.025$, partial $\eta^2 = 0.17$. Participants spent more time studying the partly-controllable than the non-controllable presentation, Tukey's post hoc $p = 0.018$. The main effect of spatial and mechanical reasoning abilities did not reach

Table 4
Mean study time in seconds (and SD) as a function of user-control and ability

	Presentation			
	1 ($n = 14$)	2 ($n = 15$)	3 ($n = 16$)	Total ($N = 45$)
High ability ($n = 22$)	136.0 (36.1)	213.3 (51.3)	179.4 (65.6)	176.2 (59.4)
Low ability ($n = 23$)	174.6 (57.1)	281.0 (97.6)	230.4 (142.5)	228.7 (111.0)
Total ($N = 45$)	155.3 (50.1)	247.1 (82.7)	206.1 (112.7)	203.1 (92.4)

1: non-controllable presentation; 2: partly-controllable presentation; 3: fully-controllable presentation. High ability: participants with high spatial and mechanical reasoning abilities; low ability: participants with low spatial and mechanical reasoning abilities.

significance, $F(1, 39) = 2{,}26$, $p < 0.14$, partial $\eta^2 = 0.06$. A significant interaction was found between presentation and ability, $F(2, 40) = 3.45$, $p = 0.04$, partial $\eta^2 = 0.15$. The low-ability participants performed better than the high-ability ones in the controllable presentations.

Because of the effect of presentation on study time, we carried out an ANCOVA with performance on the functional mental model indicator as between-subjects factor, with study time and ability (DAT mean scores) as two covariates. This analysis showed a significant main effect of study time, $F(1, 38) = 13.33$, $p < 0.001$, partial $\eta^2 = 0.26$, but no main effect of ability, $F(1, 38) < 1$, ns, or of presentation, $F(2, 38) = 0.20$, ns. Moreover, the ANCOVA showed a significant interaction between presentation and ability, $F(2, 38) = 3.51$, $p = 0.04$, partial $\eta^2 = 0.16$. This interaction indicated that participants with high ability performed less well in the two controllable presentations than the low-ability participants; on the contrary, they performed better in the non-controllable presentation. Participants with low ability had higher performance on the functional mental model indicator when compared to those in the controllable presentations. As the analysis of study time showed, low-ability participants spent more time with the controllable presentations than the high-ability ones. Therefore, study time is the critical factor when demanding levels of comprehension are posed rather than controllability by itself.

3.3. Conclusion

The controllability of the presentation by itself was not a powerful factor in improving comprehension. Hypothesis 3 that predicted higher comprehension of the functioning of the mechanical system in the two controllable presentations as compared to the non-controllable one was falsified. Experiment 2 showed also that user-controlled presentations provided participants with low ability an advantage in building a functional mental model of the three-pulley system. This advantage did not exist for participants with high ability: a non-controllable presentation appeared suitable for them. In this way, Hypothesis 4 was verified. However, the benefits of controllable presentations were a function of the increase of study time, which is necessary for low-ability learners to integrate the information regarding the dynamic mechanical system.

4. General discussion

This research aimed to compare the effects of various multimedia presentations on comprehension of the functioning of a dynamic mechanical system. Experiment 1 tested the effect of static vs. animated illustrations that were used to convey a dynamic process. Experiment 2 tested the effect of user-control of the animated presentation.

In Experiment 1, it was found that a presentation with five integrated sequential static frames of the operation of the dynamic mechanical system was equivalent (and even better than) to an animated presentation as regards the formation of functional mental model. It was also better than sequential-independent-static-frame and single-static-frame presentations. These findings cannot be explained solely by the amount of information conveyed by the different presentations, because the integrated-sequential-static-frame presentation contained exactly the same amount of information as the sequential-independent-static-frame presentation. However, in the sequential-independent-static-frame presentation each new frame representing a different step of the dynamic process caused the disappearance of the previous step; as a consequence, the perceptual continuity of the local kinematics was disrupted and this created difficulties in retaining in memory the previous micro-step while processing a new one. This probably led to a lower integration of the information across the micro-steps. The integrated-sequential-static-frame presentation, which allowed direct visual comparisons between the micro-steps of the dynamic mechanical system, produced an improvement in the functional mental model, particularly for low mechanical reasoning and spatial ability participants.

In Experiment 2 it was found that user-control of the animation did not have a powerful effect on comprehension. Other recent studies about user-control and interactivity with animation showed the same results (Bétrancourt, 2005; Boucheix, 2008; Kriz & Hegarty, 2004; Lowe, 1999, 2004). Specifically, Lowe (1999, 2004) showed that user-control of animations had no effect in tasks concerning meteorology, which is a conceptually complex task. On the other hand, Schwan and Riempp (2004) found that user-control of a video presentation had a strong effect on procedural learning. Experiment 2, which involved the same dynamic mechanical system as Experiment 1, revealed an intermediate pattern of results. Our research showed a positive effect of user-control on functional mental model only for participants with low spatial and mechanical reasoning abilities; for participants with high ability the two controllable presentations led to a deterioration of comprehension.

Several questions arise from our results that need to be discussed. The first question concerns the differences between the two experiments as regards the role of spatial and mechanical reasoning abilities. We found a "classical" effect (Hegarty, 2005) of spatial and mechanical reasoning abilities on processing mechanical content in favour of the high-ability participants in Experiment 1 but not in Experiment 2. How can it be that high spatial and mechanical reasoning abilities interfere with learning from controllable animated presentations? This kind of interference between interactivity level and expertise has already been found in the past (Bétrancourt, 2005; Paas et al., 2007). In Experiment 2, the differences between high- and low-ability participants, in favour of the latter, were related to the time spent studying the three-pulley system presentation. The high-ability participants spent less time than the low-ability ones studying the presentation. Moreover, the analysis of study time as a covariate showed a strong effect of study time but no effect of the controllability factor. Therefore, study time appeared to be the main factor that differentiated comprehension at the level of functional mental model. Of course, the use of the control features of the animation could have influenced the length of study time. Moreover, the partly-controllable presentation, which provided a segmentation of the mechanical process, might have helped low-ability participants as the integrated-sequential-static-frames presentation in Experiment 1.

On the other hand, two explanations can be evoked to explain the pattern of the high-ability participants' results in Experiment 2. One explanation could be related to a presentation-compatibility problem. The controllable animations might have generated information-delivery features that did not correctly match the dynamic internal model formed by high-ability participants, or that appeared redundant and useless. A second possibility concerns the effective use of the animation's control properties. The efficiency of user-controllability could depend on its active use by learners (Bétrancourt, 2005; Boucheix, 2008; Lowe, 2004). Learners with high spatial and mechanical reasoning abilities might have made little use of user-controllability; for example, they might have just tested how to operate the three-pulley system, using only one time and quickly the user-control device. This behaviour has already been observed with experts dealing with new designs of well-known systems (Cobb & Fraser, 2005; Rieber, 2005).

Evidently, further research concerning user-control is needed with respect to users' activities during task processing. From an educational point of view, our results suggest that, in some cases, interactive designs that might help low-ability learners are not adaptive for high-ability learners as these designs may demand that low-complexity tasks be performed by high-ability learners. This finding could be similar to the "expertise reversal effect"? Instructional techniques that are highly effective with inexperienced learners, by reducing working memory load, can lose their effectiveness and even have negative consequences when used with more experienced learners (Ayres & Paas, 2007; Kalyuga, Ayres, Chandler, & Sweller, 2003; Paas et al., 2007).

A second question that should be discussed with respect to the present findings concerns the specific mechanical content we tested. Content seems to be an important factor in the choice of visualization techniques. The segmentation design used in Experiment 1 and the controllable presentations used in Experiment 2 could be efficient for some tasks or knowledge domains but not for others, more abstract or complex ones. For example, a computer screen filled with a series of highly complex graphics could lead to a higher cognitive load than animations. Future research is needed to test this assumption.

A third question that may be evoked deals with the relationship between gender and cognitive abilities. The great majority of the participants in the present two experiments were females. Previous research showed differences between males and females as regards spatial abilities. These differences particularly concern mental rotation and manipulation tasks (Cornoldi & Vecchi, 2003; Halpern & Collaer, 2005). Gender-related factors (e.g., processing strategy) might explain some of the differences of our findings from those of other studies. However, research on DAT's Normalization Scale (the test we used in our research), showed no significant differences between males and females as regards the Spatial Relations test (DAT manual; Bennett et al., 2002, p. 46). Moreover, spatial abilities, as well as mechanical reasoning abilities, of our participants were situated in the sixth class out of 11 of the Normalization Scale of this test. Therefore, it can be argued that probably gender is not a factor that affected our findings and the explanation lies elsewhere.

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