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CT Making Sense of Animation: How do Children Explore Multimedia Instruction?

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A-Head Introduction

With the increasing sophistication of computer technologies and decreasing production costs, multimedia documents offering highly animated and interactive graphics are becoming ubiquitous in instructional materials. However, research on how learners process such multimedia information in order to construct a mental model of the learning material has emerged only in the last decade. From an applied perspective, a key issue is whether multimedia documents are actually beneficial to learning when compared with more traditional materials. It is therefore important to identify the conditions under which educational benefit is more likely to occur. From a more fundamental research perspective, many issues still remain to be thoroughly investigated. These include questions about how people process multimedia documents and what this processing may tell us about cognitive processes involved in constructing mental models.

In this chapter we focus on instructional multimedia documents that include animated graphics or animation. An instructional multimedia document can be defined as a "*presentation involving words and pictures that is intended to foster learning*." (Mayer, 2001, p. 3). More generally, words refer not only to verbal information in natural language, but also to symbolic information that can accompany graphics, such as formulae in mathematics or chemistry. For the purposes of this chapter, animation is defined as "[…] any application which generates a series of frames, so that each frame appears as an alteration of the previous one, and where the sequence of frames is determined either by the designer or the user" (Bétrancourt and Tversky, 2000, p 313). This definition encompasses not only computer-controlled animation, but also interactive animation in which the user can control the pace or the events occurring in the presentation. In this chapter, we will use the expression "animated instruction" to instructional multimedia material that includes both verbal or symbolic information and animated pictorial information. We also define learning as the construction of a "runnable mental model" (Mayer, 1989) of the to-be-learned content.

It is generally believed that animation is effective for conveying dynamic information, and consequently should improve learners' understanding of concepts involving change over time. However, research has failed to find systematic benefits from using animation to foster conceptual understanding. As with other areas of research into multimedia learning, it is vital to pose the right type of question. In this case, the relevant question is not "*does* animation promote learning?" but rather "*when* and *why* is animation likely to promote learning?" In order to understand the conditions under which animation may be beneficial to learning, further investigation is needed of how humans construct mental models from animated graphics. In the last decade or so, research has developed powerful experimental paradigms that have led to both cognitive theories of multimedia learning (Mayer, 2001; Schnotz & Bannert, 2003) and guidelines for designers (Moreno & Mayer, 1999; Narayanan & Hegarty, 2002). However, the experimental settings employed have usually involved university students studying materials “out of context.” Although this approach may be fine for investigating specific factors such as presentation and interface format, it is not suitable for capturing the behavior of actual learners in real settings. The research reported in this chapter addresses the question of how young learners in school settings study multimedia documents that include animated graphics supported by verbal commentaries. Such research is needed to provide guidelines for the design of effective multimedia instructional materials that can fully exploit the educational potential of animation. Children were chosen as participants for this investigation not only because they are a particularly relevant population of learners, but also because animation is claimed to be particularly attractive and motivating to young students. The primary purposes were to characterize the exploration behaviors that young students spontaneously exhibit when faced with animated instruction and to elicit their views on the respective roles of verbal and animated information in the instruction. A secondary purpose was to investigate whether the prospect of subsequent assessment affected students’ exploration behavior and subjective reactions.

A-Head Instructional uses of animated graphics

B-Head How visualization helps understanding

In the last two decades, a large body of research in cognitive psychology has investigated whether the widespread enthusiasm for the use of graphics in instructional material can be supported by empirical evidence as to their actual effectiveness in promoting learning. Most of the research in this area compared text alone with text and pictures in terms of subjects’ performance on retention and inference tests. The findings largely support the claim that graphics benefit learning, with most studies indicating that graphics improved memory for the illustrated information and comprehension of the situation described in the text (Denis, 1984; Levie & Lentz, 1982; Levin, Anglin, & Carney, 1987). More recently, studies have investigated the conditions under which graphics are beneficial to memorization and comprehension (Mayer & Gallini, 1990; Scaife & Rogers, 1996; Schnotz & Kulhavy, 1994).

Various reasons have been advanced to explain the beneficial effects of graphics. Some of these reasons are associated with the affective role that graphics can fulfill. For example, graphics may be aesthetically appealing, humorous, attention-attracting, or motivating. (Levie & Lentz, 1982; Peek, 1987). However, animations may also confer benefits by fulfilling a cognitive role. According to dual-coding theory, by conveying information in both verbal and pictorial codes, a double track is provided for the processing, encoding, and retrieval of this information (Kulhavy, Brandon, & Caterino, 1985; Paivio, 1986). Graphics also provide a means to use space for representing elements and their relations, be they inherently or metaphorically spatial in nature, thus taking advantage of the power of spatial reasoning and inference in human cognitive system (Larkin & Simon, 1987; Tversky, 1995, 2001). Graphics may indeed be "worth a thousand words" when one needs to describe situations that are inherently spatial and multidimensional, such as faces, maps, knots, and the like. Finally, the proponents of mental model theory assert that, ultimately, readers form a mental representation which is structurally analogical to the situation described. From such mental models, new information can be inferred, missing information completed, and contradictions resolved (Johnson-Laird, 1983). Providing an analogical visualization through a graphic is considered to facilitate mental model construction (Mayer, 1989). Schnotz and Bannert (2003) have provided an elaborated account of mental model formation in terms of how verbal-symbolic information and depictive information are conjointly and interactively processed. Graphics could also help to facilitate mental model construction by offering an external representation that supports an internal representation, thus partially offloading information from working memory and increasing available processing capacities.

B-Head Using animation to convey dynamic information: when does it work?

The characteristic that distinguishes animations from other graphics is their direct visualization of changes that occur over time. Animation is used extensively in multimedia instructional materials where it may also be designed to allow interaction. Because animations visualize temporal change, they seem particularly well suited to conveying information that is inherently dynamic, such as biological processes, mechanical systems, and physical phenomena. However, many research studies have failed to find benefits of animation over static graphics, even when the subject matter involves change over time. Morrison and Tversky (2001) compared animated graphics, static graphics, and text alone for teaching the permissible paths of people or vehicles. Graphics produced better performance than text alone, but animated diagrams provided no benefits compared to (single) static diagrams. Rieber and Hannafin (1988) and Rieber (1989) found no facilitation for animation in teaching Newton's laws of motion to elementary school students. Using multimedia instructional materials designed according to guidelines and principles derived from a cognitive process model of multimedia comprehension, Hegarty and Narayanan (2002) found no difference in learning outcomes between those who viewed animation and those who viewed static graphics. A conclusion that can be drawn from such studies is that animation is not the only type of graphic that can lead to "runnable mental model" (Mayer, 1989) of the subject matter.

Tversky, Betrancourt and Morrison (2002) examined studies in which animation was found to be beneficial to learning and concluded that in those studies, animation conveyed information that static graphics did not. For example, Thompson and Riding (1990) used an animation to explain the Pythagorean theorem to junior high school students that incorporated rotation and translation to depict equivalence in length and area. They found that students studying the animation outperformed students studying a static graphic or a series of graphics depicting important steps. In such cases, animation is assumed to be beneficial to learning because it conveys additional information that is crucial to the process of constructing a satisfactory mental model of the subject matter. This crucial information conveyed by the animation concerns fine-grained microsteps that cannot be inferred by learners who are novices in the depicted domain (Tversky et al., 2002).

Animation can be generated by computer, recorded on video from a real scene, or be formed from a mixture of real and computer-generated features. Whereas the technology should not, in itself, change the way animation is cognitively processed, the kind of information that is conveyed from the temporal nature of animation is critical to learning. Lowe (2004) distinguished three kinds of information:

– *Transformation*, that involves form changes in graphic depicted items (shape, color, and texture);
– *Translation*, that involves the movement of whole items relative to the reference frame or relative to each other.
– *Transition*, that involves the partial or complete appearance/disappearance of items, due to temporal evolution (change in the viewpoint, or having elements added or removed).

Using animation when none of these three kinds of information is required to understand the subject matter is probably inadvisable. Inappropriate use of animation may not merely fail to provide benefits, it may even be harmful to learning (Betrancourt, in press; Rieber, 1990; Rieber & Kini, 1991).

One of the main concerns for practitioners is how animation can be put to best educational use. Some of these possible uses are (Betrancourt, in press):

– *Supporting the visualization*: animation can be used to visualize dynamic phenomena that are not easily perceptible (space and time scale), impossible to realize in practice (too dangerous or too expensive), or not inherently visual (representation of abstract concepts such as forces).

– *Inducing a 'cognitive conflict'*: Animation can be used to visualize phenomena that are not spontaneously conceived in the correct fashion. Research has revealed that in physics, naïve conceptions often dominate over the scientific conceptions even amongst advanced students (Kaiser, Proffitt, Whelan, & Hecht, 1992). In such cases, using correct and incorrect animations of the phenomenon could help learners to make their conceptions explicit.

– *Enabling learners to explore a phenomenon*: Animation can be used to provide a suitable interactive learning experience that encourages learners to generate hypotheses and test them by manipulating the depiction's parameters. In this case the animation becomes a simulation that is used in a discovery-learning approach (Schnotz, Böckheler, & Grzondziel, 1999; Hegarty, Quilici, Narayanan, Holmquist, & Moreno, 1999).

B-Head Instructional uses of animation with children

Much of the more recent research into learning with animation has been carried out via laboratory experiments involving university students. In contrast, there have been relatively few experimental studies investigating the effect of animated visuals with primary or secondary school students. However, there is a large body of earlier educational research into the effect of audiovisual materials, such as television, in the classroom and some of this deals with visual information that was both animated and accompanied by narration. Because of the hypothesized developmental differences between visual and auditory encoding process and representation modes (Kail & Hagen, 1977), it was suspected that visual presentation would distract young children from the verbal (auditory) information. However, the findings with regard to text memorization and comprehension were mixed. Gibbons, Anderson, Smith, Field, and Fischer (1986) found that preschool children (4-year-olds) remembered actions better when they were conveyed visually than when they were described by a narrator, but the difference disappeared in older children (7-year-olds). Younger children also produced more elaborations with the visual presentation than with the audio alone and remembered dialogue better. It was hypothesized that the visual representation would supplement and complement developing verbal abilities, thus facilitating construction of a mental model of the referent situation. Moreover, children as young as 4 years showed unexpectedly good comprehension of cinematic montage conveying implied actions, character perspective, spatial relationships, and simultaneity of action (Smith, Anderson & Fisher, 1985). Such audiovisual research provided evidence that young children have the abilities to process animated visual information effectively and derive complex information from it.

With regard to computer animation, Rieber and colleagues (Rieber 1989; 1990; 1991a, b; Rieber and Hannafin, 1988) designed computer-based lesson to teach Newton's laws of motion to elementary school students. In some studies, a positive effect of animation was found (Rieber 1990, 1991a, b) but in others, animation was not superior to static graphics

(Rieber and Hannafin, 1988; Rieber, 1989). As was found to be the case for adults (Hegarty et al., 1999), the effects obtained were related to the instructional approach used rather than to the effect of using dynamic or static visuals (Rieber, 1990). However, animation was found to positively influence continuing motivation (Rieber, 1991a). In a free choice situation, children studying animated instruction were more inclined to return to the instruction than children studying static graphics or text instruction. Because all three instructional materials in Rieber's study were displayed on a computer, this result cannot be explained by the attractiveness of the computer tool.

As indicated earlier, the key issue is not whether animation is beneficial to learning but rather *when and why* animated instruction may be effective. Addressing this issue requires further investigation of the cognitive processing of interactive, dynamic visualizations.

B-Head Online processing of animation

To date, few studies have investigated the on-line processing of educational resources that feature animated graphics. One reason that researchers have tended not to tackle this area is that there are methodological impediments because online cognitive processes are not accessible through standard measures or simple observation. Both online and offline approaches to the collection of process data have been proposed. Online methods involve the recording of indicators such as interrogation behavior, whereas offline methods include approaches such as collecting learners' retrospective accounts of the processing activity they engaged in during task performance. Lowe (2003, 2004) analyzed meteorological novices' approaches to extracting information from a weather map animation showing how meteorological features change over time. Participants first studied animated weather maps and then predicted the future pattern of meteorological markings on a blank map without the aid of animation. After completing the prediction task, learners ‘replayed’ a demonstration of how they interrogated the animation while at the same time explaining the actions they had taken. Attention tended to be devoted to meteorological features in the animation with high perceptual salience, to the neglect of thematically relevant features with comparatively low perceptual salience. Similar processing biases in novices’ extraction of relevant information have been identified for static graphics (Zhang, 1997). Using records of interrogation activity and participants’ commentaries on the replay of their performance, Lowe (2004) further analyzed the strategies used by students in processing the animation. He distinguished four *spatial* strategies (exclusive, inclusive, intra-regional, interregional) according to the area explored and the extent of the spatial relationships involved. In addition, four classes of *temporal* strategies were considered (confined, distributed, abstractive, integrative) according to the time period explored and the extent of the temporal relationships involved. The meteorological novices who participated in that study tended to use low-level strategies focused upon specific locations and specific periods while neglecting more inclusive dimensions.

In traditional primary and secondary education, the emphasis tends to be on verbal material as the main vehicle for presenting to-be-learned information, whereas depictive information is too often merely used for attracting and motivating students. A study by Holliday (1976) confronted this issue by designing an instructional situation in mathematics in which the graphics conveyed the critical information. He found that children studying the graphics alone outperformed those studying these graphics in association with text. Holliday concluded that children in school situations in which text and graphics are presented together tend to ‘underprocess’ the graphic information, because they think that the most critical information is conveyed by the text. In contrast, Kalyuga, Chandler, and Sweller (2000) found that providing a combination of verbal and pictorial material improved learning performances for novices trade apprentices compared with pictorial information only. However, as learners became more experienced, the pictorial material alone was more beneficial than the verbal-pictorial combination. According to the authors, providing verbal explanation for learners who no longer needed it induced a redundancy effect that resulted in cognitive overload. Although these findings do not conflict with the positive general multimedia effect found in numerous studies, they do provide evidence that "more can be less" when learners possess sufficient prerequisites to take advantage of a single representational format. Under such circumstances, processing of unnecessary verbal information may prejudice processing of the pictorial information.

It has also been suggested that insufficient processing of pictorial information may have a negative effect on learning from animated graphics, a phenomenon described by Lowe (2004) as 'underwhelming.' Such an effect could come about if an animation induces an *illusion* of understanding, due to its visualization of the whole chain of events, but does not result in comprehension of the functional and causal relationships involved. Comprehension of an animated presentation may also be compromised if learners lack the conceptual and strategic skills required to extract relevant information. Despite the optimistic claims of some semiologists (e.g., Vandendorpe, 1999), it is doubtful whether today's 'Multimedia Age' children have developed skills and, attitudes with respect to graphic information that are radically different from those of their predecessors.

A-Head Research questions

A fundamental determinant of the potential of animation to positively affect multimedia learning is the learner's capacity to process the animated information successfully (Lowe, 2004). Previous studies by Lowe (2003, 2004) found that novice learners tend to apply ineffective strategies when interrogating complex, interactive animation. However, the research also provided evidence that adults' exploratory behaviors were systematic rather than random with a number of distinctive (yet inappropriate) search patterns being exhibited. If adults fail to adopt appropriate strategies when interrogating animations, the question arises as to how successful children are likely to be in a similar situation Given that children are one of the main targets for educational animation, this is an important but neglected educational issue.

The present research investigated how children aged 12 to 13 years navigated a multimedia learning environment that offered both text and animations. In this study, information in these two representational formats was displayed separately and organized in a weak linear structure. The following questions were addressed:

i. Do young learners invoke systematic strategies when studying the available information or do their strategies reflect opportunistic navigation? What is the nature of the strategies used?
ii. Do these learners favor text or animated information?
iii. What views do the learners report regarding their exploration of the multimedia material and the specificity of each representational format?

These issues were investigated using an experimental study in which participants (7th grade students) were asked to study a multimedia document explaining the retrograde motion of the planet Mars as seen from the Earth. Two conditions were compared. Participants in the *assessment* condition were told that at the end of the study period, they would be tested on what they had learnt. For those in the *no-assessment* condition, there was no mention of a subsequent test. We assumed that the prospect of an assessment would affect the previously mentioned questions in the following way:

i. The students in the *assessment* condition would be expected to use a more systematic strategy for studying the material and more often go back to pieces of information already explored.

ii. Students in the *assessment* condition would be expected to pay more attention to text than to animation because in primary and secondary education, formal assessments traditionally give more emphasis to verbal than to depictive information.

The approach used in this study investigated strategies from a broad rather than an in-depth perspective focusing on few participants (contrast with Lowe, 2004). All actions that students took while working with the instructional material were automatically recorded on an individual basis. Participants were not asked to provide retrospective commentaries on their behavior but instead at certain points, the students were asked to nominate a reason for their actions from alternatives provided in a multiple choice questionnaire. Our objective was to identify a broad range of strategies that children use, irrespective of individual and contextual factors, and so a large number of varied participants was involved. Further, because our focus was upon strategies, the effect of animation on learning outcomes was not investigated. Indeed, investigation of learning outcomes would imply careful attention in designing the instructional material to promote conceptual understanding (e.g., Narayanan & Hegarty, 2002), design of a control condition, and control on previous learning in the domain.

A-Head Method

B-Head Participants and design

A total of 218 seventh grade students (12 to 13 years old) participated in their usual classrooms through a web-based program to which their teachers had been introduced by the experimenter. Because the participants regularly used computers at school, they were accustomed to all the required basic interface operations. Teachers volunteered to have their classes participate in the experiment and were given written instruction to be read to the participants. In cases of technical faults or other problems with the procedure, data from the participants concerned were not taken into account. The experimental design involved one between-subjects factor with two levels (*assessment* vs. *no-assessment*) with 130 participants in the *assessment* condition and 88 in the *no-assessment* condition.

B-Head Material

The material was developed using Macromedia Flash program for the client side, and php mySQL database languages for the server-side. Once launched, the presentation ran automatically without intervention from the teacher or experimenter. Presentation was the same in both conditions and consisted of an identification screen, a multiple-choice questionnaire, then the instructional material. After the instructional material, participants completed the same multiple-choice questionnaire a second time. The identification screen asked the participant for some identification data (first name, school, name of the teacher) and while the protocols were subsequently de-identified, students were asked for their names in order to provide credibility for the assessment condition. The multiple-choice questionnaire consisted of six questions about astronomic facts presented in the instructional material, one question about the relative value of text and images in instruction, and four text and picture questions on relative motion. The instructional material explained the apparent retrograde motion of Mars. It opened with a navigation panel (see Figure 7.1) displaying the 16 phases of the instruction, each phase consisting of a short animation (5 seconds on average) and a short text piece (one to three sentences). The animated segments either depicted the relative position and motion of the planets in the solar system, or presented changes in viewpoint from an earth to a solar system perspective. They were logically sequenced so that the explanation in each segment directly followed from the content in its predecessor. However, students could use the navigation panel to choose which part of the instruction they wanted to study and so work through the segments in any order they wished. The semi-circular shape of the navigation panel was chosen with the intention of breaking up the implicit linear order of a straight line. No fixed study time was set for each piece of text, and animation pieces could be run as many times as desired. Whenever a text was chosen, a 'metacognitive regulation box' opened that asked why the participant was choosing either to proceed or to remain at the same step (see Appendix to this chapter). No indication was given that a piece of information had already been studied, apart from a "last click" indication signaling the final piece of information was being visited (to avoid disorientation).

B-Head Procedure

Prior to commencement, the teachers verified that participants were unfamiliar with the retrograde motion of Mars. Students participated individually in their normal computer classroom, the size of which varied depending on facilities at the school. Participants were randomly assigned to one of the two experimental conditions and the written instructions read aloud by the teacher before the experiment. In the *assessment* condition, students were told that they were to study an instructional document on the retrograde motion of Mars in order to prepare for a subsequent test. In the *no-assessment* condition, students were given the same general instructions but were not told they would be tested afterwards. However, participants in both conditions answered the same post-test questionnaire at the end of the experiment. After answering the pre-test questionnaire, a transition message appeared: "Thank you. Now you are going to enter the navigation panel. Here you can study text or animation for each step of the explanation." The students in both conditions studied the instructional material for a total of 20 minutes. Finally, they completed the post-test questionnaire at their own pace.

B-Head Data analysis

Patterns of participants' navigation through the instructional material were first analyzed on an individual basis by graphing the pieces of information visited against time (actually, the student's clicks ordered by time). Figure 7.2 shows an example navigation pattern.

The y-axis represents the identifying number of the information piece (1 to 15 for text, 16 to 35 for animation) whereas the x-axis shows the click numbers ordered by time. In the example, the student clicked 61 times, first looking only at the animation pieces (click 1 to 14), then shifting to a systematic strategy where both the text and animation pieces were studied for each step. Strategies were identified and characterized according to: (a) the way the student partitioned exploration between the two representational formats (e.g., one after the other, all pieces in one representational format and then all in the other one, etc.) and (b) the regularity with which the student worked through the logical sequence of pieces (e.g., either in the suggested order or in reverse).

A-Head Results

B-Head Type of exploration strategies

The first question addressed in this investigation was whether children invoked systematic strategies in studying such material or not. Systematic strategies are evidence of a goal-directed behavior from which underlying cognitive processes and metacognitive regulation can be hypothesized. From the graphical representation of exploration patterns, 51 categories were initially distinguished which were then conceptualized in terms of in five broad types of strategy. Table 7.1 provides a short description and an example of each strategy type.

About one fifth of the observed patterns did not correspond to any of these main strategy types. These students adopted an apparently aimless approach, or seemed to switch between strategies more than once.

B-Head Frequencies of each type of strategy

As well as identifying the main strategy types used by participants, it is also important to know the relative frequency with which each strategy was used and whether the prospect of an assessment had an effect on strategy choice. Table 7.2 summarizes the percentages of participants using each strategy.

The most frequent strategy was *Systematic alternation* between the two representational formats in which the students followed the exploration order suggested by the display and paid attention to both sources of information for each step. The students tended to study the animation before the text (62% vs. 38% of the patterns in this category). *Successive study* was the second most common strategy and involved all pieces in one representational format being explored before exploration was shifted to the other format. Because this would appear to work against the making of making relations between the corresponding verbal and animated pieces of information, this is a somewhat surprising finding. The third strategy, *One representational format only,* is also rather unexpected because half of the provided information is ignored. However this strategy included 16.5% of the patterns, which represented about one student in six. Most patterns in this category involved the study of the animation only. In very few cases (1.5%, corresponding to only 2 of the 218 students) the students studied text information only. *Weak alternation* and *strategy shift* strategies were uncommon (respectively 6.4% and 3.2%). In most cases (5 out of 7 patterns), once students had shifted to alternation, they studied the text before the graphical information.

The second issue was whether the adoption of a particular strategy was affected by the prospect of receiving and assessment. A Chi-square computed on the number of protocols falling into each of the six main categories (the five strategies plus the undetermined category) revealed a significant difference in the distribution of patterns as a function of the condition ($\chi^2_{(5)} = 12.6$, $p < .05$). Because we expected that students in the *assessment* condition would explore the material in a more systematic way, the two conditions were compared with regard to the number of students using an identifiable strategy against the number of students whose strategy was not identified (undetermined category). The Chi-square revealed a marginally significant difference ($\chi^2 = 3.37$, $p = .066$). However, when we excluded from the identifiable strategies the "weak alternation" category, which is the least systematic and the most questionable, we found a significant difference between the two conditions ($\chi^2 = 4.98$, $p < .05$). Moreover, instances of shifting from one representational format to alternation appeared only in the *assessment* condition.

Because some patterns did not seem to follow the exploration order suggested by the navigation panel display, subsequent analysis was performed in order to determine the extent to which the students followed the display's regular left-to-right progression. Irregular patterns were produced by 11.9% of the participants (corresponding to 26 patterns). The most frequent of these was a progressive exploration followed by a regressive exploration (12 patterns), consistent with working around the border of the navigation panel's circular shape. In the previous analysis, all such patterns were placed into the *successive study* category. The students studied all pieces in one representational format in the progressive order then the other representational format in the regressive order. It is unclear whether those students appreciated that the pieces of information in each side of the navigation panel were related together (see the display in Figure 7.1). The reverse order exploration (regressive then progressive) was observed only twice (0.9% of the observations). Four students (1.8% of the patterns) explored the material in the reverse order, which meant going from right to left, ignoring the starting indication that was located on the left. Finally, 8 patterns (3.7% of the patterns) did not follow any regular progression, all being categorized in the undetermined strategy. No appreciable differences in the order of exploration were found between the *assessment* and *no-assessment* conditions.

B-Head Integration of text and pictorial information

The second main question was whether the students favored text or pictorial information and to what extent the prospect of an assessment affected this behavior. First, the percentages of the total number of information segments studied by each student that were either text segments or animation segments was computed on an individual basis. Table 7.3 compares these percentages across the two conditions.

Contrary to our expectations, these results show a tendency to favor the animated information in both conditions with no tendency to study more text information in the *assessment* condition. Further, there was no difference between the conditions in the time spent studying the text information.

Finally, we computed the percentage of participants who tackled the text information before the graphic information when studying each step on the first time, irrespective of the strategy they invoked. Again, we found very similar proportions across condition (44% in the assessment condition and 45% in the no assessment condition). In other words, a slight majority of students chose to study the animated information first, but no effect of condition was observed.

A-Head Metacognitive questions

Two short questionnaires were administrated before and after the study phase in order to assess students' attitudes toward verbal and pictorial information. When asked before studying the material which representational format (text or pictures) they thought explained the best, 50% subjects nominated pictures as more effective than text, whereas only 3% favored the text. The remaining 47% of participants considered that the text and pictures explained equally well. After studying the material, the number of students favoring the text increased to 10%.

Reflexive questions in the series of so-called 'metacognitive boxes' presented to the students while they navigated the instructional material were intended to give insights into the motivations underlying their navigation. Because the students gave an unequal number of answers, the observed differences could not be tested for statistical significance. At their first click on the navigation panel, students were asked whether they had any idea about how they were going to proceed. Thirteen percent of the students said they had very precise idea and 19% a general idea, whereas 68 % responded that they did not know yet. No difference between conditions was observed.

During navigation through the instructional material, a box popped up asking why the student chose to study a piece of information concerning a step other than the step just studied, or why the choice was made to remain on the same step, whichever was the case. When choosing to explore another step, 67.6% of the answers in the *assessment* condition and 60.2% in the *no-assessment* condition were that they 'had a good understanding of the step just studied and wanted to proceed with the instruction.' Of the remainder, 13.5% of students answered that they were just curious (17% *no-assessment* and 10% *assessment*).

The pattern of answers regarding the reasons for choosing to study the other piece of information (text or animation accordingly) in the same step was more differentiated: 53.4% of the students reported that they understood well but sought confirmation; 24.2% of the students reported that they were not sure of their understanding and needed complementary information; and 12.8% of the students reported that they were just curious (10.2% chose none of the aforementioned reasons). No difference between the two conditions was observed.

Finally, when the students chose to run a piece of animation more than once, a question asked why they decided to do so. The box did not appear if the student visited a different piece of information before running the animation another time. The results are presented in Figure 7.3.

The most frequent reason for studying an animation segment again was that the students found it unclear. Students in the *assessment* condition mentioned that the animation was too fast more often than students in the *no-assessment* condition. Students in the *no-assessment* condition more often chose reasons related to the “positive” motivations (pleasant and explanative) than students in the assessment condition.

No data could be collected on the reasons why students decided to reread a piece of text information because the text information remained on the screen until the student decided to close it.

A-Head Discussion

Young students were provided with animated instruction explaining the apparent retrograde motion of Mars as seen from Earth. The instructional material contained 15 steps, each consisting of a piece of animation and a piece of text that could not been studied simultaneously. Navigational access to the pieces of information was displayed in a semi-circular shape with buttons for choosing text or animation segments arranged along its borders. Two conditions were compared: In the *assessment* condition, students were told that there would receive an assessment test afterwards, whereas in the *no-assessment* condition, the test was not announced.

The first question concerned whether children invoked systematic strategies to explore the animated instruction. Approximately 80% of the students invoked a systematic strategy, which is higher than may have been expected for students this age given the lack of specific instruction about the regularity and unusual shape of the navigation panel. Five strategies were identified with respect to how students explored the mutually referring information in the two representational formats. The most frequently used strategy was a systematic alternation between the text and the corresponding animated information. Only one third of the students chose to explore pieces of information in both representational formats consecutively for each step. One student in five adopted a strategy that involved studying all steps in one representational format only and then all steps in the other. Although learning performances were not evaluated here, this successive strategy could be considered as likely to be comparatively ineffective because, according to the 'contiguity principle' (Moreno & Mayer, 1999) or 'integration principle' (Chandler & Sweller, 1991), the mutually referring text and animated information should be treated as closely as possible to each other in space and time. Unexpectedly, we found a significant number of students (16.5%) ignored one of the representational formats, typically the text information. In contrast to the investigations by Holliday (1976) or Kalyuga et al. (2000), verbal and pictorial information in the present study were not redundant for novices in the domain. Apart from the basic arrangement of planets that students might already have known before the experiment, animation and text were complementary, each representational format being critical to comprehension of the other in most of the steps. With regard to temporal exploration of the material, most students adopted a regular progression through the instruction, following the order suggested by the starting indication and the circular shape. This comprehensive approach differs from that found by Lowe (2004) because we did not observe any 'confined strategies' in which the focus was limited to only particular aspects of the available information. However the display in Lowe's study was a continuous animation, not a set of discrete pieces. Nevertheless, like Lowe, we found evidence of inappropriate exploration with half the students using a *successive study* strategy consisting of a progressive order followed by a regressive order. This approach was completely counter to the fact that the text and visual information were highly complementary and so intended to be processed together.

The second question concerned whether children favored one or other of the representational formats (text or animation). The results gave some support for Vanderdope's (1999) assumption that children are attracted by visual representational formats. In two thirds of the alternation strategy patterns, the animation was studied before the corresponding text information. This attraction to animation may not be detrimental because there is evidence that studying the visual before the verbal is better than the opposite (Baggett, 1984). Apart from two students, all of the 15% who studied one representational format only chose animation and ignored text information. Moreover, students overall studied in average slightly more animation than text information (54% vs. 46%). These results are consistent with previous studies on both computer animation (Rieber, 1991a) and audiovisual material (Smith, Anderson, & Fisher, 1985), indicating that children can be strongly attracted by animation, even in school situation.

Our third question concerned children's views on learning from verbal and pictorial information. When asked which representational format offered the best explanation, they predominantly chose pictures over text, which is consistent with the assumption of an attraction for visual material. Students tended to justify their exploration behavior in terms of achieving increased understanding, and very rarely in terms of pleasure or curiosity.

Finally, we expected that the prospect of a subsequent assessment would encourage systematic exploration and a preference for verbal information. We found a significant effect of the condition on the type of strategy adopted by the students. Students who expected a test more often chose to follow a systematic strategy (*systematic alternation*, *successive study*, *one representational format,* or *strategy shift*) than did students in the *no-assessment* condition. Moreover, we observed the *strategy shift* category only in the assessment condition which may indicate students realized midway that they had to consider both sources of information in order to fully understand the explanation. Contrary to our expectations, we found that students in the *assessment* conditions neither paid more attention to text information, nor explored more pieces of information. The reasons given by students concerning their choice of information did not provide evidence of a clear contrast in the motivations underlying the students' behavior in the two groups. Differences were observed regarding the reasons for choosing to run an animation again, with the students in the *assessment* condition tending to report an understanding-based motivation whereas those in the no assessment condition tended to report a pleasure-based motivation. It is possible that the students did not consider the assessment as very important because it was not being given by their own teacher.

The types of exploration behavior found in this study were probably affected by the particular format of the instructional material. First, the strict separation of text and animated information for each step may have led students to assume that one representational format was sufficient for understanding the explanation. Second, the unusual circular shape of the navigation panel may have created an impression of circularity, thus inducing what was called irregular exploration (progressive order in one representational format than regressive order for the other). Further, this exploration order, which from a perceptual perspective could be considered as tracing around the navigation panel's border, may have been adopted to avoid disorientation in a quite complex instructional display. Finally, the metacognitive boxes may have provoked metacognitive regulation processes, that led to more frequent systematic strategies than would otherwise have been the case.

In conclusion, the results of this experiment showed that despite their young age, most of these students adopted a systematic strategy when exploring the multimedia document. However, less than one third of the students adopted what would be considered as an ‘effective’ strategy (as defined by multimedia learning research). Most of the students did not use strategies that would allow complementary text and graphic information to be processed conjointly and progressively, a requirement for fully understanding the explanation. Fifteen percent of the students chose to ignore the text information completely, although this proportion was slightly lower for those who expected a subsequent assessment test. Given the explanative and computational power of visualization (Larkin & Simon, 1987; Tversky, 1995, 2001), children’s attraction towards visualization is potentially beneficial for learning, provided that appropriate guidance is given in the instructional material. In particular, the material should indicate clearly that verbal and pictorial information are both necessary to fully understand the explanation and so should be processed conjointly. In practical design terms, this means that the verbal information (preferably auditory than written) should be provided in a way that it cannot be avoided or overlooked. If the instructional material provides a navigation panel, the spatial layout should clearly indicate the order in which the pieces of information need to be studied, regardless of aesthetic or artistic issues. Finally, further research is needed to investigate the role of metacognitive prompts that could engage children to reflect upon their exploration strategies.

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A-Head Appendix

Question asked in the 'metacognitive regulation boxes' (translated from French).

1 You are at the beginning of your exploration and
   a. You have a precise idea of the order in which you are going to explore the pieces of information
   b. You know roughly in which order you are going to explore the material
   c. You do not know exactly, you will see.
2. You decided to run this animation again because
   a. It was too fast
   b. It was not clear
   c. You find it pleasant
   d. You find that it explains well
   e. Other reason
3. You decided to remain on this step because
   a. You think you understood well and you wish to find a confirmation
   b. You are not sure you understood well and you want to find complementary information
   c. You are just curious, there's no particular reason
   d. None of the three propositions
4. You decide to explore another step because

a. You think you understood this step well and you want to proceed

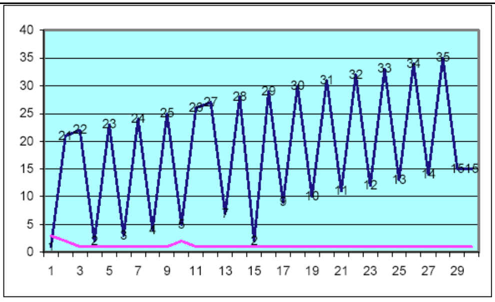
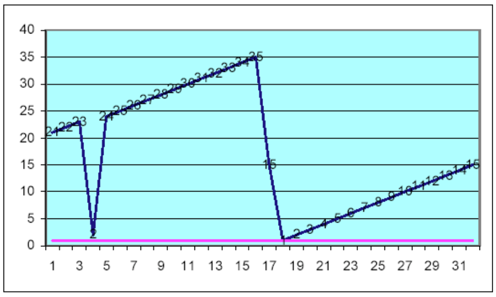
b. You are not sure you understood this step well and you hope that the new step will provide complementary explanations.

c. You are not sure you understood this step but you think that it is not necessary to understand.

d. You are just curious, there's no particular reason

e. None of the propositions above.

Table 7.1 *Exploration strategies identified in the protocols: description and examples of pattern*.

Name of the strategy	**Description**	**Example**
Systematic alternation	Systematic alternation between the text and the animated information. In the example, the student started by viewing the animation before reading the text.	
Successive study	Successive study of the two representational formats. In the example, the student first explored all animated pieces and then studied all text pieces.	

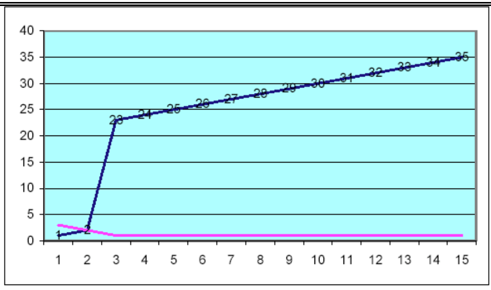
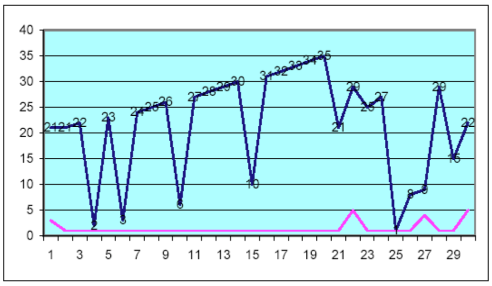
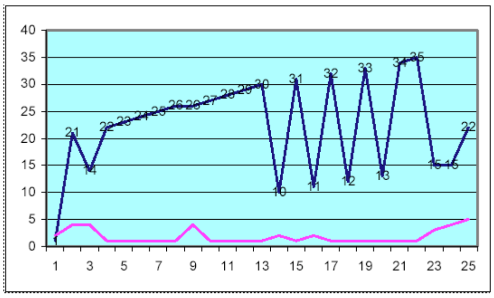
One representational format only	Only one representational format was explored while the other was ignored. In the example, the student explored only the animated information	
Weak alternation	The students explored text and animation pieces alternately, but in a less systematic way than in the systematic alternation strategy.	
Strategy shift	The student shifted from a one representational format strategy to systematic alternation strategy. In the example, the students explored all animated pieces and then shifted to alternation at the end of the explanation.	

Table 7.2 *Percentage (number in parentheses) of exploration patterns falling into each category.*

Strategies	**Assessment**	**No assessment**	**Total**
Systematic alternation	36.9% (48)	22.7% (20)	31.2% (68)
animation then text	23.1% (30)	14% (12)	19.3% (42)
text then animation	13.8% (18)	9% (8)	11.9% (26)
Successive study	20% (26)	25% (22)	22% (48)
animation first	14.6% (19)	18.2% (16)	16% (35)
text first	5.4% (7)	68.2% (6)	6% (13)
One representational format	16.1% (21)	17% (15)	16.5% (36)
Animation only	14.6% (19)	17% (15)	15.6% (34)
Text only	1.5% (2)	0	0.9% (2)
Strategy shift	5.4% (7)	0	3.2% (7)
Weak alternation	4.6% (6)	7.9% (7)	6% (13)
Anim. – text	4.6% (6)	6.8% (6)	5.5% (12)
Text – anim	0	1.1% (1)	0.4% (1)
Undetermined	16.9% (22)	27.3% (24)	21.1% (46)
Total	*100% (130)*	*100% (88)*	*100% (218)*

Table 7.3 *Percent pieces of text and animated information studied and mean number (and standard deviation) of clicks averaged across subjects in the two conditions*

	Conditions	
	Assessment	**No assessment**
Animation % total	54%	54%
Mean number	17.8	17.1
SD	*4.2*	*3.8*
Text	46%	46%
Mean number	15.3	14.5
SD	***9.6***	***7.3***
Overall mean number of clicks	33.1	31.7
SD	*13.5*	*9.6*

A-Head Figure Captions

Figure 7.1. The navigation panel displayed for exploring the instructional material. Each of the 15 phases consisted of one piece of text and one piece of animation. In-picture captions: Problem statement (in the framed box), animation (above the curved line), text (below the curved line), and last click with the arrow, indicating the final piece of information visited.

Figure 7.2. Example graphical representation of a student's navigation pattern.

Figure 7.3. Reasons for deciding to run the piece of animation again.