Metacognition in understanding multimedia presentations

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Abstract: The symposium is aimed at highlighting the role that the awareness about the mental processes which are activated and the control over such processes play in comprehending and memorizing notions presented through texts and pictures. The attempt is to support the notion that promoting metacognition could improve the effectiveness of multimedia tools. In fact, metacognition should bring students to develop adequate strategies to learn from text-picture combinations. The contributions included in the symposium present a set of different ways of interpreting the links between metacognition and multimedia learning and show a series of experimental approaches that can be followed to investigate such links.

This symposium is aimed at exploring relations between metacognition and multimedia learning. We focused particularly on the role that the awareness about the mental processes which are activated and the control over such processes play in comprehending and memorizing notions presented through texts and pictures. The symposium relies on the assumption that promoting a metacognitive attitude could improve the effectiveness of multimedia tools (Mayer, 2005). As Mayer (2001) pointed out, the different channels and structures through which information is presented can support meaningful learning, allowing many different strategies to be used in the access and handling of information. However, there is the risk that students underestimate the cognitive potential of multimedia tools. Successful outcomes in multimedia learning environments are hence dependent not only on the multimedia tools themselves but also on their ability to foster the development of the necessary metacognitive skills in order to promote deep information processing and enhance the acquisition of well-defined knowledge structures (Mayer, 1999). A metacognitive attitude could bring the student to develop a strong awareness towards the tool, the specific task, and the content he/she is learning, as well as adequate strategies and an effective self-regulation.

The contributions included in the symposium address the above mentioned issues, so to present a set of different ways of interpreting the links between metacognition and multimedia learning and to show a series of experimental approaches that can be followed to investigate such links. The first paper explores how mental representations are actually built depending on the order of presentation of the multimedia stimuli. The second contribution investigates changes in students' awareness of the strategies they followed in learning from static and dynamic multimedia presentations. The third paper analyzes how learners are accurate in predicting and assessing retrospectively their performance. The fourth contribution explores students' awareness of the reasons which lead a student to integrate spontaneously verbal information with pictures and the strategies he/she applies to do so. The four papers focus on progressive levels of metacognition. In the first paper learners were given no explicit hint at inducing a metacognitive attitude. In the second paper explicit questions about the *strategies* activated were given *after* the task was carried out. In the third paper metacognitive questions concerned the *outcome of the strategies* and were given *before* performing the task. In the fourth paper metacognitive reflections about the *relevance of the strategies* were suggested *during* the task.

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The Dynamic of Constructing Mental Representations: A Neglected Aspect in Research on Multimedia Learning

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Objectives and Theoretical Framework

Recent theories of multimedia learning have emphasized that successful teaching and learning with multimedia is only likely to occur, if the constraints of human information processing are adequately taken into account. Accordingly, instructional multimedia design has to be adapted to the human cognitive system. However, different theoretical approaches on multimedia suggest different ways how this should be done. In the following, three approaches will be analysed in more detail: Cognitive Load Theory (Sweller, 1999), the Cognitive Theory of Multimedia Learning (Mayer, 2005), and the Integrated Model of Text and Picture Comprehension (Schnotz & Bannert, 2003; Schnotz, 2005).

Cognitive Load Theory (CLT) emphasizes the limitations of working memory and suggests that any interaction among cognitive elements in working memory should remain within these limitations. The same suggestion is also made by Mayer (2005) in his Cognitive Theory of Multimedia Learning (CTML). Provided that learners need in fact multiple sources of information, the Integrated Model of Text and Picture Comprehension (IMTPC) suggests the same design principles as the CTML, except for very difficult text, which should generally presented in a visual rather than in and auditory format. Furthermore, the IMTPC makes some further predictions, which are not shared by the other two approaches: Because picture comprehension is considered as a structure mapping process, the structure of visualization is assumed to affect the structure of the mental model, which in turn affects learning results with specific tasks (Schnotz & Bannert, 2003). An inadequate visualization format can therefore hinder rather than improve learning.

Although these design principles are based on empirical research, it is not possible to apply them under all circumstances. Complex subject matter needs generally complex text and complex pictorial displays, which cannot always be presented in an integrated format or with high spatial contiguity, respectively. Instead, the different displays need to be presented sequentially rather than contiguously. However, even in case of optimal spatial contiguity of written text and pictures, there is a need for sequential processing. The necessity of splitting the learner's visual attention between two sources of information requires also some sequential processing, because the learner has to shift his/her attention at some points from the text to the picture and back again. In other words: If written text is combined with pictures, verbal and pictorial information can never enter working memory simultaneously and, thus, sequential effects are likely to occur. Therefore, the question arises whether verbal and pictorial information interact differently in working memory, when they are processed in different orders: How is text comprehension affected by previous picture comprehension, and how is picture comprehension affected by previous text comprehension? Is the relation between text processing and picture processing a symmetrical or an asymmetrical one?

Method

If two information sources are processed sequentially, there seem to be three basic possibilities: (a) independence, (b) replacement, and (c) stimulation. In case of independent processing (a), the second information source is processes in the same way and with the same intensity as it would be without the previously presented first source of information. Although this assumption is not very plausible, it is an implicit part of the multimedia principle: Students are assumed to learn better from text and pictures than from text alone, because the pictures are assumed to be processed in addition to the text, and the text is not processed less deeply although the pictures have already been processed. In the case of replacement (b), the second information source is processed less deeply than if it had been presented first: The first source replaces the second to some extent and, thus, information from the second source is ignored or processed less deeply. In the case of stimulation (c), the second information source is processes more deeply than if it had been presented first: The first source leads to additional questions and, thus, triggers additional processing of the second source. Based on this distinction, the research question mentioned above can be specified as follows:

- Is a picture followed by a text processed with the same intensity (independence) or with lower intensity (replacement) or with higher intensity (stimulation) than if it had been presented first?
- Is a text followed by a picture processed with the same intensity (independence) or with lower intensity (replacement) or with higher intensity (stimulation) than if it had been presented first?
- Are these effects dependent on learners' and task's characteristics?

The contribution will present research results from a series of learning experiments, which were dealing with sequential effects of text processing on picture processing and vice versa.

Results

Basic findings are:

- Learners with lower learning prerequisites are more likely to follow a replacement strategy, that is, to process the second source of information less intensively after having processed the first source.
- Learners with higher learning prerequisites are more likely to follow a stimulation strategy, that is, to process the second source of information more intensively after having processed the first source.

- Presenting a picture before the corresponding text is more beneficial than presenting the text before the corresponding picture.
- Presenting a picture before the corresponding text is more likely to have a stimulating effect on text processing than text presentation before the picture presentation.
- Text presentation before picture presentation is more likely to have a replacement effect on picture processing than picture presentation before the text presentation.

Discussion

Regarding the general question, whether the relations between text and pictures are symmetric or asymmetric, the findings clearly support the asymmetry view. Accordingly, text and pictures have fundamentally different roles in knowledge acquisition from multiple representations. Thus, there are fundamental asymmetries between verbal and pictorial information with regard to the construction of mental representations. As the three models of multimedia learning presented above have different views on sequencing effects, the results provide also different amounts of support to the models.

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What Strategies Do Students Use When They Learn Science with Static and Dynamic Visual Representations?

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Objectives and Theoretical Framework

The purpose of the reported study was to investigate the role of students' metacognition in learning from a multimedia program that included either static or dynamic visual representations of astronomy phenomena. In this research, we define metacognition as individuals' knowledge and control of their cognition and focus on one dimension of students' metacognitive skills: strategy use. Past research has shown that the combination of narrated explanations with pictures or animations is most effective in promoting learning, a finding that has been called the multimedia principle (Moreno & Mayer, 2007). The theoretical rationale underlying the multimedia principle is that when words and pictures are presented simultaneously, students have an opportunity to construct verbal and visual mental models of the system-to-be-learned and to build connections between them. Although building connections between verbal and pictorial representations is an important step in conceptual understanding (Schnotz, 2005), this process can be particularly challenging because it requires students to set learning goals, determine which strategies to use, assess whether the strategies are effective, and evaluate their emerging understanding of the topic (Azevedo, 2005).

It is well-documented that most students do not have adequate metacognitive skills, particularly at deeper levels of comprehension that require explanatory reasoning (Graesser, McNamara & VanLehn, 2005). A promise of multimedia environments is that, despite their complexity, they can help circumvent students' metacognitive limitations by prompting them to use specific study strategies during learning. For example, cognitive load researchers have found evidence for the imagination effect, the finding that students learn better when asked to imagine the material to-be-learned (Tindall-Ford & Sweller, 2006). The present study extends on this research by testing the hypothesis that providing students with explicit instructions to visualize static or animated astronomy models would promote their comprehension of the causal relationships implied in the multimedia lesson. In addition, we were interested in answering the following research questions:

1) What strategies do students report using when learning from multimedia programs?
2) Does instructing students to use an imagination strategy result in greater self-report of imagination?
3) Do students report using different strategies when learning with static or animated graphics?

4) What is the relationship (if any) between the self-reported study strategies and students' study time and learning?

Method

The participants were 120 college students from the American southwest who learned about the seasons of the Earth with two multimedia versions: animated graphics with narrated explanations (A) and static graphics with narrated explanations (S). Groups A and S were given three different strategy instructions: to close their eyes and imagine the bodily relationships (I or internal representations); to watch the bodily relationships (E or external representations); and to think about the bodily relationships (T). Students were randomly assigned to learn in one of 6 randomly assigned conditions. Learning was measured with a comprehension test after learning. In addition, and of primary interest to this proposal, we coded the participants' responses to the following strategy-use question "Did you use any strategies to answer the prior questions?" "If so, can you describe what strategies you used?" Two independent scorers unaware of the condition of the participants scored students' comprehension test and coded the strategy-use question using the following emerging categories: imagination, retrieval of prior knowledge, use of program images, logical reasoning, several strategies, and no strategy.

Results

What strategies do students report using when learning from multimedia programs? The presence or absence of each strategy was dichotomously scored. The following percentages of participants reported using each strategy: 8.3% imagination, 20.8% prior knowledge, 13.3% program information, 1.7% logical reasoning, 9.2% several strategies, and 46.7% reported not using a strategy.

Does instructing participants to use imagination as a study strategy result in greater self-report of imagination? A Chi-square analysis was performed on each strategy category to determine whether associations between the S, A, I, W, and T conditions and type of strategy used were apparent. Although we expected that participants would report a higher use of imagination in the I condition, all analyses were non-significant ($ps > .10$).

Do students report using different strategies when learning with static or animated graphics? We found a significant association between the A condition and reporting the use of program images (26% and 8% of students in A and S conditions, respectively), $X_1^2 = 6.54$, $p = .01$, and $\varphi = .23$.

What is the relationship (if any) between the self-reported study strategies and students' study time and learning? An ANOVA using time as a dependent variable and study strategy type as a factor revealed that type of strategy use was a significant predictor of time spent on the learning materials $F(4, 113) = 6.33$, $p < .001$ and $\eta^2 = .18$. Post hoc comparisons with a Bonferroni adjustment revealed that students who reported using imagination spent significantly more time than those who reported no strategy use ($p = .01$, Cohen's $d = 1.15$) and those who reported using several strategies spent significantly more time than those who reported no strategy use ($p < .001$ and $d = 1.38$). No other statistically significant differences were apparent.

An ANOVA using students' comprehension scores as a dependent variable and study strategy type as a factor indicated that type of strategy use was a significant predictor of students' comprehension, $F(1, 13) = 3.91$, $p = .005$, and $\eta^2 = .12$. Follow-up tests revealed that students who reported using imagination had significantly higher scores than those who reported no strategy ($p < .01$; $d = 1.24$).

Discussion

Four results of the study are of interest. First, it is surprising that almost half of the participants (46.7%) reported not utilizing a strategy when learning from the complex multimedia materials. This finding is in line with past research showing that many students do not show adequate metacognitive skills in activities that require explanatory reasoning (Graesser, McNamara & VanLehn, 2005). Second, contrary to our expectations, although the instructional program prompted the use of imagination to the I group and prompted students to watch the materials during the lesson to the W group, no association was identified between the I and W conditions and strategy usage. A possible explanation for this finding is that our prompts may have been to vague to effectively instruct students in the strategy usage. Third, students in A group reported significantly more using the graphics to help their learning than those in S group, suggesting that animations are more likely to be retrieved during subsequent tasks. Fourth, participants who reported using imagination or two or more strategies required more time with the materials relative to those who reported using no strategy. This suggests that if students are encouraged to utilize metacognitive strategies that instructors should be aware that more time may be required. Importantly, when compared to the no strategy group, participants who reported using imagination scored higher in comprehension and no different than those who reported using a combination of strategies, suggesting that focusing on a visualization strategy in multimedia learning may be more efficient than combining multiple strategies. Further implications and potential extensions of the research will be discussed in our final presentation.

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Understanding Metacognitive Biases in Complex Tasks

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Theoretical Framework and Objectives

Effective learner control requires that learners are adept at understanding their knowledge acquisition process, that is, engage in metacognitive processes such that they are able to accurately monitor and evaluate their comprehension of the material (e.g., Fiore & Salas, 2007; Schraw, 1998). Notably, individual differences in metacognitive skills are especially influential in these environments, given the lack of instructor intervention. If, due to inaccurate metacognitive awareness, trainees overestimate their comprehension, instruction may be terminated prematurely, leading to ineffective transfer of training and poor task performance. Metacognitive processes may also interact with characteristics of the trainee, such as verbal ability. As such, a major goal of training should be to assist trainees, particularly low ability learners, in monitoring their subjective learning experience (i.e., supporting their metacognitive processes), in order to facilitate overall performance.

In the present contribution we reanalyzed the results of a prior experiment where metacognitive accuracy was examined in a complex training tutorial (on the principles of flight) using performance predictions and postdictions in conjunction with verbal aptitude. We addressed how metacognitive processes interact with learning outcomes when training for complex tasks in order to develop a better understanding of metacognition in distributed learning environments. The general paradigm involves training that incorporates differing methods of information presentation with tests designed to tap specific components of knowledge. Our goal was to understand the degree to which metacognition accuracy may vary as a function of both verbal aptitude and the nature of the test. In particular, our prior research on complex task training varied the difficulty of the test questions such that they required differing amounts and forms of knowledge integration. Some of the questions were straight-forward assessments of declarative knowledge, that is, they evaluated participants' mastery of basic declarative knowledge about the concepts presented in a training tutorial, whereas others required the integration of multiple concepts to be answered correctly. Specifically, for our "integrative knowledge" measure, a question would provide a multimedia animation of an airplane maneuver and participants had to identify the instrument primarily affected, along with the main airplane parts used and the axis on which the maneuver was taking place (see Cuevas, Fiore, & Oser, 2002; Fiore, Cuevas, & Oser, 2003).

Metacognitive accuracy was determined by taking the value of the difference between overall performance and prediction and/or postdiction to calculate an individualized measure of the accuracy of their self-assessments of understanding. The magnitude of this score, what we refer to as the metacognitive bias score, indicates the degree to which participants are able to monitor their understanding of complex task material (i.e., larger scores mean poorer ability) while the direction of the score (positive or negative) indicates whether they overestimate or underestimate performance. Bias scores are often used by researchers investigating the accuracy of learners' assessments – for example, looking at measures of relative accuracy, that is, the degree to which predicted performance correlates with actual performance (e.g., Dunlosky et al., 2002). We evaluated, first, how learners' bias scores varied in a correlated manner with their actual performance, and second, how individual differences in ability may influence the magnitude of learners' metacognition bias.

Method

The purpose of this study was to investigate the influence of instructional strategies in supporting learners' knowledge acquisition and metacognition of complex systems, in this case, aviation training. Sixty-one undergraduate students participated in this experiment for course credit (25 males and 36 females, mean age = 22.66 years). Naïve participants were used in this study. An interactive instructional tutorial based on the principles of flight was created for this study, adapted from standard pilot training manuals (Jeppesen Sanderson Private Pilot Manual, 1996). A knowledge assessment task was developed to separately assess acquisition of two distinct types of knowledge, namely declarative and integrative. Our first set of questions (declarative) assessed participants' mastery of basic declarative concepts associated with the training tutorial. Our second set of questions (integrative) assessed participants' ability to integrate task knowledge. This is a less common form of assessment requiring trainees to apply their newly acquired knowledge in a variety of multimedia based task-relevant scenarios. The nature of the material presented in the tutorial required understanding and integration of complex concepts and relations. Therefore, since verbal comprehension ability has been shown to be indicative of skill acquisition of a complex task, Part 1 (Verbal Comprehension) of the Guilford-Zimmerman Aptitude Survey was administered to assess the influence of individual differences in verbal ability in comprehending the concepts in the tutorial. After completing measures of individual differences (i.e., demographic information such as age and gender, verbal comprehension), all participants received multimedia computer-based instruction on the basic principles of flight using the tutorial created for this experiment. Upon completion of the tutorial, the metacognitive prediction question was administered. To measure the accuracy in their self-assessment of performance, participants were asked to report how well they thought they did on the test overall. Participants were then presented with the knowledge assessment task, followed by the metacognitive postdiction questions. For the postdiction questions, the query was given separately for the declarative and the integrative test questions.

To document the relation between metacognition and task performance, we first correlated bias scores with actual performance. Overall, prediction bias was negatively related to actual performance on the knowledge test (composite score of the knowledge assessment questions), $r = -.57$, $p < .01$. Postdiction bias, overall, was also negatively related to actual performance, $r = -.54$, $p < .01$. Additionally, postdiction bias was negatively related to actual performance, for both the declarative questions, $r = -.58$, $p < .01$, and the integrative questions, $r = -.55$, $p < .01$. Thus, participants poor in metacognition accuracy tend to perform worse (i.e., the greater the bias, the lower the performance). Next, we analyzed the differences in bias scores for participants of differing verbal ability. Specifically we compared the individual bias scores of the high and low verbal participants. Overall, the difference in prediction bias scores between HiVA (MHiVA = -.39) and LoVA (MLoVA = .34) participants was significant, $t(56) = 2.57$, $p < .05$. Additionally, overall postdiction bias scores between HiVA (MHiVA = -.26) and LoVA (MLoVA = .22) participants were also significantly different, $t(56) = 1.72$, $p < .05$. Last, the difference in postdiction bias scores for the integrative knowledge questions (HiVA = -.31 and LoVA = .32) was significant $t(56) = 2.11$, $p < .05$, but it was not significant for the postdiction bias scores for the declarative knowledge questions (HiVA = -.12 and LoVA = .18).

Discussion

This study documents the utility of using bias scores as a method of gauging the accuracy of participants' metacognition ability. In line with recent studies, we found individual differences related to participants prediction and postdictions (Maki et al., 2005). We first found that metacognitive bias is negatively related to performance and second, that the difference in bias scores between high and low verbal ability participants was greater with the more difficult measures. Thus, when complex tasks and complex testing procedures are involved, differences between populations may be exacerbated. In particular, in addition to what was shown by Maki et al. (2005) with variations in learning material, we add to this literature by showing that differences in metacognitive bias may be related to variations in test type and related to verbal aptitude. Specifically, when looking at the postdiction bias scores, there was not a significant difference between high and low verbal ability participants on the declarative measure but there was a significant difference on the integrative measure. As such, it may be that when multiple concepts from the training content must be combined for a correct response (as in our integrative questions), low verbal ability participants still have difficulty in their postdiction assessments of performance. Finally, the bias scores consistently revealed that low verbal ability participants were overestimating their performance while high verbal ability participants were underestimating their performance. Overall, these findings are important for both theoretical and practical reasons. First, from a theoretical standpoint, we document the utility of assessing metacognition using distinct measures in order to elucidate the manner in which metacognition may be hindered with learners, in general, and those varying in ability, in particular, when using complex training and testing environments (i.e., measures beyond standard declarative questions). These bias scores document the relation between poor metacognition and lower task performance. Second, from a practical standpoint, the consistent overestimation of performance by low verbal ability participants suggests avenues for remediation with respect to self-paced or automated learning environments.

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Metacognition, Strategies, and Cognitive Styles during the Spontaneous Fruition of a Multimedia Presentation

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Theoretical Framework and Objectives

In technology-supported learning the role of metacognition is necessary to ensure to the user the chance of taking the best advantage of the instructional tools (e.g., Cuevas et al., 2002, 2004; Kramarski & Ritkof, 2002; Van den Boom et al., 2004). Technological instruments should be ideally calibrated according to the user's characteristics. Where the user is lacking of some skills, technology should complement his/her abilities; when the user is already suited, technology should enhance his/her skills. Obviously, tool designers can not always devise tools which can meet the characteristics of all kinds of users. So, it is needed that the users themselves calibrate the tools according to perceived features of the tools and on the basis of the awareness that they have about their personal skills.

As far as multimedia tools are concerned (Mayer, 2005), it is important to know what users believe about the possible advantages provided by text-picture combinations and how they control the access to pictures by identifying relevant strategies which allow them to inspect a picture when it is needed. The main aim of this study was to investigate the spontaneous strategies employed by undergraduates in learning through a multimedia presentation and the awareness which accompanies such strategies. A further goal was to assess whether individuals' cognitive styles influence their behaviour and awareness in exploring a multimedia environment.

Method

By taking a multimedia presentation used by Mayer (2001) in his experiments as a reference prototype, we devised two new presentations focused on different topics, but comparable to Mayer's regarding text length, structure, and complexity. We constructed a presentation explaining how an invisibility cloak works and another one explaining how to change frets on a Renaissance lute. Each presentation had been divided into 16 short passages. A picture, illustrating what was described in the text, was associated to each passage.

For each topic an audio format (with the text read aloud) and a video format (with the text written on the computer screen) were devised. A total of 4 presentations were obtained (2 text topics x 2 formats). Each participant was faced with two presentations (invisibility cloak and lute), one in the audio format and the other one in the video format. The order of presentation of the two topics and of the two formats was counterbalanced, so that each topic was combined to each format the same number of times and each topic and each format occurred as first and second presentation the same number of times. During the presentation of each topic, the participant, while listening to the text or reading it, could ask for the corresponding picture by pressing a key every time he/she believed to need it.

The participants' requests for pictures and the specific timing of such requests had been recorded automatically. Afterwards an interview occurred in order to lead participants to make explicit the evaluations which induced them to ask for pictures. Finally they were tested on comprehension of the contents of the two presentations (the questions were built on the model of Mayer's test questions).

A sample of 24 university students (girls = 20, boys = 4; age: 20-34, mean = 23), attending to different faculties, joined the research. The administration of the SOLAT (Torrance, 1988) and of a questionnaire devised by Antonietti and Colombo (1996-1997) allowed us to assess participants' cognitive styles (by distinguishing, respectively, between analytic and intuitive thinkers and between low and high visualizers).

Results

Concerning participants' behaviour held along the presentations, we noticed that a lower number of pictures were requested in the text than in the audio format ($F_{1, 22} = 4.22$, $p < .05$), especially when the topic of the presentation was simpler. Nevertheless, in the text format participants were slower ($F_{1, 22} = 4.30$, $p < .05$), perhaps because they took more time for reading the text.

Concerning learning results, the audio format promoted better responses ($F_{1,22} = 4.28$, $p < .05$). Learning outcomes appeared to be linked to the amount of pictures requested along the presentation: in the audio format participants who seldom asked for pictures answered correctly a lower number of questions (mean = 5.57) than students who often asked for pictures (mean = 8.44).

As far as cognitive styles were concerned, intuitive thinkers generally rated the picture to be more useful and to accelerate comprehension, coherently with their style. Analytic thinkers, conversely, recognized that pictures hinted at mental visualization, a strategy that they did not tend to apply spontaneously.

Discussion

This study allowed us to observe that students, when faced with a multimedia presentation and being free to explore it as they like, tend not to respect Mayer's (2001) principles. Furthermore, undergraduates rated differently multimedia formats, using different cognitive strategies to explore them. This different evaluation was not general, but concerned also single aspects, as the type and the number of pictures and the topics.

According to what emerged in the interviews, pictures were considered as more useful in the text format, where contents were also considered to be easier. We would have expected that with a more complex content, pictures could help more. This apparently contradiction can be explained arguing that, when the text is perceived to be quite easy, pictures are used with a vicarious role to the text, so to prevent people to read all the words of the text carefully. In the audio format the topics were rated to be less familiar than in text format. If compared with the previous finding, this result stresses the coherence in metacognition by showing that easiness ratings mirrored familiarity ratings.

As far as learning outcomes were concerned, we realized that the audio format promoted better retention. This can be interpreted according to Mayer's theory (which induces to predict that the simultaneous presentation of text and pictures produces dangerous interference), even though it can also be maintained that, since more demanding conditions appeared to promote more complex cognitive processes, the audio format stimulated the spontaneous activation of higher attentive resources.

Hence, we can say that individual assessment of the learning condition appears to influence learning performance, as well as individual cognitive differences. It is interesting to notice how more complex situation appear to promote a more effective metacognition.

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