Chapter 9

Computer Technologies in Powerful Learning Environments: The Case of Using Animated and Interactive Graphics for Teaching Financial Concepts

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Introduction

What is a powerful learning environment? Simply stated, it is an environment that generates high learning gains for its users. Does this means that the label "powerful" can only be allocated a posteriori through empirical testing? No, otherwise we would simply call it an "effective" learning environment. The term powerful refers to potential learning outcomes and is hence based on the learning theory that supports this prediction. Subsequently, the meaning of powerful varies according to learning theories. A powerful learning environment is built on a hypothetical causal relationship between the environment features and the learning processes. For instance, a socio-cultural designer would qualify an environment as being powerful according to the forms of social interactions that are supported. Within a mastery learning perspective, it is rather the possibility to adapt instruction to the learner needs that would legitimate the word powerful. For a behaviorist, the controlled delivery of information and the possibility to deliver immediate feedback would justify the same label. The purpose of this book is precisely to articulate the tuning of technology issues with the learning process.

From a cognitive science perspective, powerful refers to many aspects, but a core issue is the mapping between the computational model of the domain and the mental model to be constructed by the learner. The relationship between these two models is of course not a simple 'copy-from-disk-to-brain' mechanism but a complex process based on interactivity and visualization. Interactivity is the core "powerful" mechanism in pedagogical simulations. Nevertheless, learners have multiple difficulties with efficiently conducting this hypothetico-deductive process (de Jong & van Joolingen 1998).

Powerful Learning Environments: Unraveling Basic Components and Dimensions

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What about visualization? One key advantage of technology is to be able to visualize dynamic models as animated pictures. Do animations and interactive animations contribute to make computers into powerful learning environments? Intuitively, the answer is positive but empirical findings are contradictory. This contribution addresses the cognitive benefits of using animated pictures in a course.

This effectiveness of animated pictures belongs to basic research since, as we will show in this chapter, it questions the way dynamic processes are mentally represented. At the same time, this concerns a very practical point in the design of virtual learning environments, namely, the added value of electronic lecture notes. Electronic documents provide powerful search facilities, links to other documents, possibilities to compile pieces of text and so forth, but they suffer from several drawbacks such as navigation difficulties (Rouet 2000), poor annotation facilities and poor readability both in terms of speed and tiredness (compared to paper). One of the specific advantages of electronic documents is the possibility to include animated pictures and interactive animations. However, the intuitive superiority of animated and/or interactive pictures over static ones has failed to be confirmed by empirical studies. We report here an empirical comparison of animated and static pictures, interactive or not, in a course on financial analysis.

Learning from Multimedia Instruction

A considerable body of research has demonstrated the benefits of adding graphics for comprehending text instructions (Mandl & Levin 1989; Schnotz & Kulhavy 1994). However, the underlying cognitive processes have not been clearly identified yet. The theoretical explanation generally admitted assumes that graphics help people constructing a mental model of the described object or concept, insofar as they provide an analogical support upon which the mental model can be elaborated (Mayer 1989; Schnotz 2001).

With rapid computer technology advances, multimedia instructional materials and resources are becoming increasingly available from primary to higher education. However, multimedia design features are more often based on aesthetic or practical considerations than on concerns about how people actually learn. In the last decade, research carried out in the mental model theoretical frame has begun to provide guidelines for designing multimedia instruction based on cognitive theories and experimental results (Hegarty *et al*. 1999).

In the mental model paradigm, learning performance is investigated using retention and transfer tests. A retention test aims at controlling the memorization of explicit information in surface representations (i.e. propositional representation and mental image of the text and pictures explanation). A transfer test, which requires learners to infer new information from the explanation, aims at measuring the construction of a correct mental model of the content presented. The mental model theoretical frame admits that text and pictures are processed in order to build surface representations, which are then integrated with previous knowledge to form the mental model of the concept conveyed (Mayer 2001; Schnotz 2001). In this paradigm, deep learning means the construction of a "usable" mental model that enables people to solve transfer problems.

Dynamic Visualization Devices and their Effect on Learning

Computer animation cannot be considered as one clearly defined visualization device. There can be many types of animation, going from the movie-like video clip to the abstract simulation of the results of an equation. Just as various forms of graphics can have various effects on learning, we claim that different types of animation may lead to different cognitive effects. In order to be able to generalize the findings, research must precisely define the type of animation used in terms of delivery issues (e.g. interactivity, information displayed) as well as in terms of content (e.g. realistic vs. schematized). Gonzales (1996) defined animation as: "*a series of varying images presented dynamically according to user action in ways that help the user to perceive a continuous change over time and develop a more appropriate mental model of the task*" (Gonzales 1996: 132).

Two issues arise from this definition. First, animation is a continuous flow of information, which may generate cognitive difficulties for learners (Lowe 1999). Second, computer animation requires users to interact with the device. The level of users' interaction is a key factor in animation effectiveness (Rieber 1989).

Sequential Display as an Alternative to Continuous Animation

Animation should be expected to be effective for conveying processes such as weather patterns, electric circuits, biological mechanisms or the mechanics of a bicycle pump. However, the literature reports many outright failures to find benefits of animation, even when animation is used for conveying change over time (Bétrancourt & Tversky 2000). Tversky *et al*. (2002) examined these intriguing findings in terms of cognitive processes and found that animation can overwhelm human perceptual and conceptual capacities. Moreover, animation is cognitively demanding, since it requires learners to simultaneously construct a mental model, attend to the animation and memorize previous states. Principles to enhance the conceptual value of animation and to decrease cognitive load are proposed in Bétrancourt & Tversky (2000).

The research carried out so far failed to demonstrate clear advantages of using animated graphics over static ones on learning. Another way to take advantage of the dynamic features of computer technologies is to display sequentially the elements of text and picture instruction. The sequential display is then used to convey the organization and inherent logic of the instruction, just as a teacher draws and explains a schema on the blackboard in a carefully chosen sequence. Moreover, according to Mayer's integration model (2001), gradually providing elements enables learners to construct local representations and then to integrate them in a coherent mental model, whereas providing all information at once could lead to cognitive overload. Previous research has demonstrated that the order in which elements of a spatial configuration were mentioned in the text had a dramatic effect on the quality of the mental model participants elaborated (Denis & Cocude 1992). As for graphics, the findings of our first studies (Bétrancourt *et al*. 2000) tended to show that sequential display had no effect on pure memorization but did positively affect the performance on transfer tasks.

Interactivity in Practice and Instruction?

Computer animation usually entails user interaction. Interactivity can occur on two levels: In practice and in instruction. In practice, the level of interactivity, defined as learners' activity, increases when the information displayed varies as a function of the learners' input. The animation then aims at encouraging learners to generate and test hypotheses. According to constructivist theories, deep learning is more likely to occur when learners are engaged in active interaction with the instructional material. Gonzales (1996) designed a study to evaluate interactivity in an animated instruction and found that an increased level of interactivity significantly improved the learners' accuracy and enjoyment in a decision-making task. However, Kettanurak *et al*. (2001) found that the higher the level of interactivity, the lower the improvement in performance, though learners found the high interactivity mode the most enjoyable. This result called into question the ability of students to effectively monitor their learning activity.

Secondly, interactivity in instruction can be defined as the possibility to act on the pace of the animation. In two experiments, Mayer & Chandler (2001) investigated the effects of simple user-controlled interaction on learning: The animation was segmented into meaningful 8-second-sequences, and, after each sequence, learners had to click on a button to run the next sequence. The results of the two experiments showed that learners performed better on a transfer test when they controlled the pace of the presentation. Moreover, students who first received the presentation with control followed by the presentation without control performed better than students who received the two presentations in the reverse order. Thus, inserting interactivity per se did not improve learning. Rather interactivity improved learning only when it is inserted in a way that is consistent with how people learn. The control over pacing enabled learners to incorporate all information of a frame before proceeding to the next. In other words, interactivity decreases cognitive load and enables the formation of a local mental model, which can subsequently be integrated when the whole presentation is provided. These results are consistent with cognitive load theory (Sweller & Chandler 1994), which states that cognitive overload impairs learning, as well as with the two-stage construction of a mental model, which claims that learners first build local mental models, and then incorporate these local models into one integrated representation.

Research Hypotheses

An experimental study was carried out in order to compare three display conditions, according to whether the elements were displayed all at once or sequentially, and to whether the computer or the learner had the control over the display order. The learning material was a multimedia lesson on financial analysis, containing graphics and corresponding text. The study took place within a regular class session.

A main assumption of this study is that sequentially displaying the elements of a multimedia explanatory document will facilitate learning for two reasons. First, presenting information sequentially avoids perceptual and cognitive overload, since learners can gradually integrate the given information. Second, the display order acts as a processing guide, with information displayed sequentially in a meaningful order, just as a teacher draws a schema on the blackboard while explaining its different elements. Taken together, these two advantages will facilitate the construction of a mental model of the concept conveyed in the instruction.

Regarding interactivity, we distinguished two levels. Interactivity in instruction was set to the minimal control mode: after each element was displayed, the presentation stops until the learner chooses to resume. Mayer & Chandler (2001) showed that this minimal level of control had a dramatic positive effect on learning, compared with no control. As for interactivity in practice, two alternative hypotheses may be raised. A previous study on the sequential display of graphics (Bétrancourt *et al*. 2000) showed that when the display order was relevant, learners tended to elaborate a mental model consistent with the organization conveyed. According to this view, providing learners with a relevant order will help them to more easily construct a coherent mental model of the concept, than if they were to choose the order in which elements should be displayed themselves. Alternatively, previous research on interactivity has shown that when learners studied in an exploratory mode, they are more inclined to engage in an active learning strategy. According to this view, learners who are given the control over the next element to be explained will learn more deeply than learners who do not.

Method

Participants

Participants were 81 undergraduate students engaged in the first year of a business school in Grenoble (ESCG). They were randomly assigned to a static group ($n = 26$), a sequential non-interactive group ($n = 27$), and a sequential interactive group ($n = 28$). The experiment took place during a regular course but the participation was on a voluntary basis. All students had followed a class on the basics of accounting balance the semester before, but none of the learners was acquainted with financial analysis.

Material

The material was made up from the teaching materials of two teachers in financial analysis at ESCG. The material consisted of 13 pages. Four pages contained texts and graphics explanations and nine pages contained test questions. The explanation pages described the construction of an accounting balance sheet and its transformation into a financial balance sheet, using the proper computation of financial indicators.

Three versions of the material were designed. The test pages were identical across conditions, but the pages with explanations varied:

- In the sequential non-interactive condition, the order in which elements were displayed was defined by the instructional designer and computer-controlled.
- In the sequential interactive condition, the order in which elements were displayed was under learner's control.
- In the static condition the elements appeared simultaneously on the screen with all text available in an adjacent window (with a scroll bar if necessary).

In the two sequential conditions, elements of the graphics were displayed in a random order at the bottom of the screen (see Figure 1). In the non-interactive condition, when the learner clicked on the *Next* button, one of the elements moved to the correct location in the graphics and the corresponding explanatory text appeared on the right-hand part of the page. In the interactive condition, the learner had to click on each one of the elements instead of the *Next* button to have it moved to the correct location and receive the explanation.

In the sequential conditions, the text built up gradually in the right-hand frame, whereas it was displayed all at once in the static condition. However, for page 1, only the text corresponding to the last selected item was displayed in the sequential condition, because the complete text was more than one page long.

Procedure

Participants were tested in groups of 15 to 18 students during the regular class slot, individually seated in front of a computer. The students first signed a consent form explaining the purpose of the study. Then they followed the instruction given on the computer screen and proceeded at their own pace. After they indicated their age and previous courses, they read the instructions explaining the five phases of the study. The first phase consisted of three pages that explained the construction of an accounting balance, the computation of a financial indicator, and the transformation from an accounting balance to a financial balance sheet. Then followed four multiple-choice questions, for which they could read the explanation pages again. In the second phase, participants were asked to compute the financial index of a company from the accounting balance sheet. They could *not* refer back to the explanation pages. In the third phase, a second set of explanation pages on financial analysis was provided. The fourth phase consisted of two tests and was identical for all conditions. The first test was an interactive manipulation task for which students had to graphically reconstruct a financial balance sheet by direct drag-and-drop of the items provided on the bottom of the screen. If the location of the item was not correct, it was moved back to its original place. After three trials it was moved automatically to its correct location. The second test was a set of four transfer questions about the comparison of two companies in terms of financial analysis. In the fifth and final phase, participants were asked to rate the material according to three parameters: enjoyment, difficulty and pedagogical value. The whole experiment took 30 to 45 minutes to be completed. The program

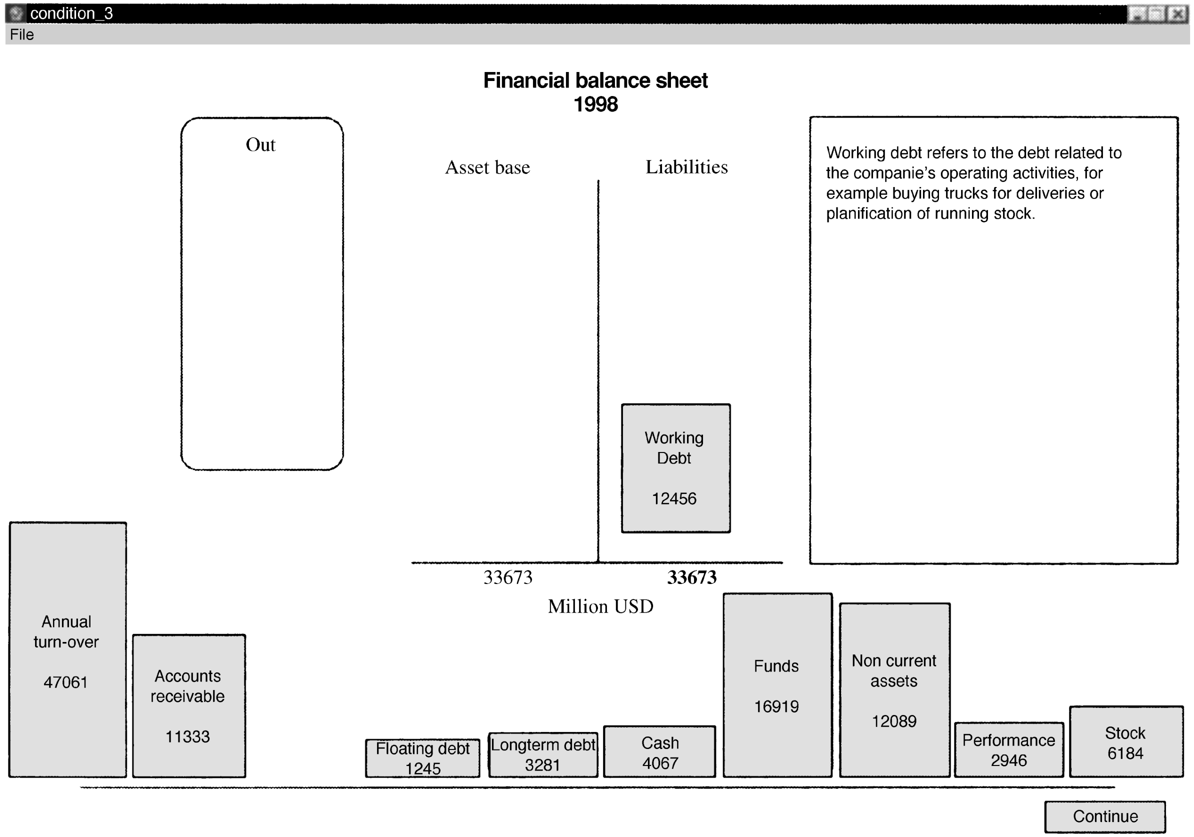

Figure 1: Explanation page on the balance sheet in the sequential interactive condition. The learner has clicked on the element "Asset base". The corresponding block has moved to its location in the schema and the explanatory text has appeared in the right-hand frame.

automatically recorded time on explanation pages and time and answers to test pages. In the manipulation task, the order in which items were selected was also automatically recorded.

Results

Study Time

Study time includes time to read the first three explanation pages and to answer the four multiple-choice questions. The four questions aimed at helping students in processing the explanations more deeply. As they could refer back to the explanations while answering, the rate of correct responses was very similar across conditions (static: 67.3%; sequential non-interactive: 67.3%; sequential interactive: 67.9%). Table 1 displays the time spent on the first phase, making a distinction between the initial study time and the time to read back the explanations and answer the questions.

Data show that learners in the sequential non-interactive condition spent some more time at studying the instruction and answering the questions than both the static and sequential interactive conditions. However, an analysis of variance (ANOVA) did not confirm the significance of differences between groups ($F(2,78) = 0.873$, *NS*).

Computation of the Financial Index

After they answered the four multiple-choice questions, learners had to compute a financial indicator (Working Capital Need or WCN). Now, they could *not* refer back to the explanation pages. Table 2 displays the time required to compute the indicator and the percentages of correct answers.

Table 2 shows that learners in the sequential interactive condition were fastest to compute the indicator ($M = 113$ secs), followed by learners in the static condition ($M = 131$ secs) and, finally, learners in the sequential non-interactive condition ($M = 152$

Table 1: Time spent (in secs) on studying the explanations.

	Static		**Sequential non-interactive**		**Sequential interactive**	
	M	***SD***	***M***	***SD***	***M***	***SD***
Initial reading	190	*111*	259	*91*	195	*74*
Questions	179	*64*	191	*84*	201	*80*
Total	368	*159*	450	*147*	396	*103*

Table 2: Time (in secs) and performance on computing the financial index (WCN).

	Static		**Sequential non-interactive**		**Sequential interactive**	
	M	***SD***	***M***	***SD***	***M***	***SD***
Computing time	131	*42*	152	*72*	113	*50*
Percentage of correct answers	81%	—	89%	—	68%	—

secs). ANOVA indicated a significant effect ($F(2,78) = 3.26$, $MSE = 23834.46$, $p < 0.05$). A post-hoc test using Fisher's PLSD indicated a significant contrast between the two sequential conditions, $MSE = 38.79$, $p < 0.05$. The percentage of correct answers seemed to show the reverse pattern, but this difference is not statistically significant ($\chi^2 = 3.74$, *NS*).

Time and Performance for Constructing a Financial Balance

The second test task consisted of an interactive drag-and-drop task, in which learners had to construct a financial balance sheet. The time spent on the task and the number of errors are displayed in Table 3.

Table 3 shows that learners in the sequential non-interactive condition spent less time and committed fewer errors than learners in the other two conditions. An analysis of covariance (ANCOVA) computed on the time spent on the task with the number of errors as a covariate indicated a significant effect ($F(2,75) = 3.22$, $MSE = 6739.76$, $p < 0.05$). A post-hoc test using Fisher's PLSD yielded a significant difference between the two sequential conditions and the static condition (sequential non-interactive vs. static: $MSE = 37.41$, $p < 0.05$, sequential interactive vs. static: $MSE = 29.38$, $p < 0.05$).

Table 3: Mean time (in secs) and number of errors in constructing the financial balance sheet.

	Static		**Sequential non-interactive**		**Sequential interactive**	
	M	***SD***	***M***	***SD***	***M***	***SD***
Manipulation time	146	*56*	109	*37*	117	*51*
Number of errors	7.00	*2.84*	5.18	*2.73*	6.96	*3.07*

Table 4: Time (secs) and performance for the four transfer questions.

	Static		**Sequential non-interactive**		**Sequential interactive**	
	M	***SD***	***M***	***SD***	***M***	***SD***
Answering time	820	*270*	969	*297*	898	*373*
Mean score[a]	0.29	*0.28*	0.61	*0.34*	0.52	*0.47*

[a] Answers were rated on a 3-point-scale. 0 = incorrect or missing; 1 = correct but incomplete; 2 = correct.

Transfer Test

The last test task consisted of four transfer questions on financial analysis. Two independent evaluators rated the answers on a 3-point scale according to the correct answers given by an expert in financial analysis. The agreement was 95% and cases of disagreement were cleared up by a short discussion. Time data for one student were lost due to technical problems. Table 4 displays the answering times and the mean scores for the four questions.

As displayed in Table 4, learners in the sequential non-interactive condition spent more time to solve the inference questions than learners in the sequential interactive condition, but the differences were not statistically significant. (ANOVA computed on answering times with questions (1 to 4) as a repeated measures, $F(2,77) = 1.30$). Regarding the accuracy of learners' answers, participants in the sequential non-interactive condition and, to a lesser degree, the sequential interactive condition outperformed participants in the static condition. Figure 2 displays the mean scores for each separate question.

Though mean scores were quite low, a similar pattern of performance can be observed for each question, with learners in the two sequential conditions outperforming learners in the static condition. ANOVA computed on individual scores with question (1 to 4) as a repeated measure indicated a significant difference between conditions, $F(2,78) = 5.16$, $MSE = 2.95$, $p < 0.01$). A post-hoc test (Fisher's PLSD) showed that the sequential groups differed significantly from the static group (static vs. sequential non-interactive: $MSE = 0.323$, $p < 0.001$; static vs. sequential interactive: $MSE = 0.238$, $p < 0.01$).

Subjective Evaluation

Finally, learners were asked to rate the instructional material according to three criteria: enjoyment, difficulty and pedagogical value. Table 5 displays the results of this evaluation.

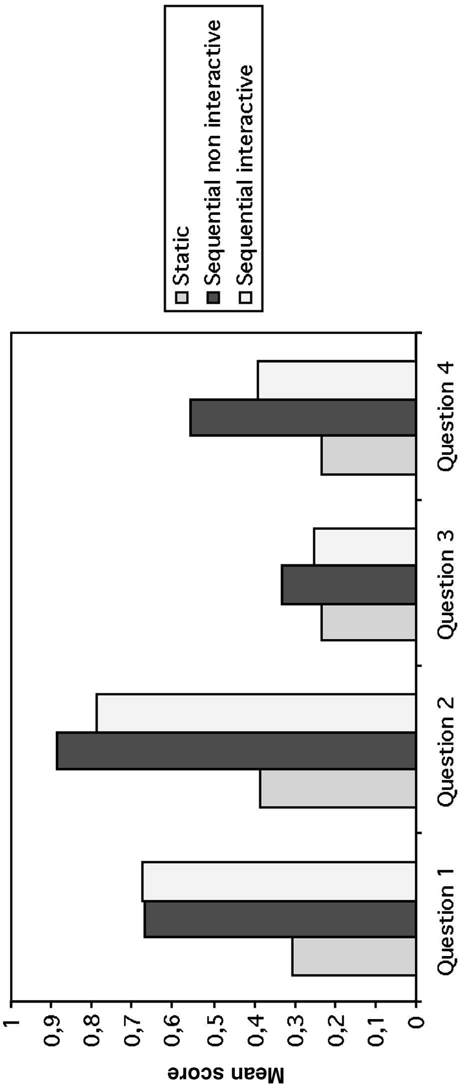

Figure 2: The mean scores for the four separate transfer questions.

Table 5: Subjective ratings of the material on a 6-point Lickert scale (1 = very low and 6 = very high) according to three criteria: enjoyment, difficulty and pedagogical value.

	Static		**Sequential non-interactive**		**Sequential interactive**	
	M	***SD***	***M***	***SD***	***M***	***SD***
Enjoyment	3.38	*0.94*	3.86	*1.22*	3.06	*1.60*
Difficulty	3.74	*0.89*	3.25	*0.81*	3.39	*1.36*
Pedagogical value	2.86	*1.45*	3.35	*1.50*	2.04	*1.66*

Regarding *enjoyment*, ANOVA showed that the effect of the format was not statistically significant ($F(2,77) = 2.62$). The ratings of *perceived difficulty* were quite similar across groups and the differences were not statistically significant ($F(2,77) = 1.5$). As for pedagogical value, the sequential non-interactive group was the most positive, compared to the static and the sequential interactive group. ANOVA showed that the effect of the format was statistically significant ($F(2,77) = 4.96$, $MSE = 11.76$, $p < 0.01$) and Fisher's PLSD indicated a significant contrast between the two sequential conditions ($MSE = 1.31$, $p < 0.005$).

Discussion and Conclusion

The experimental study reported above aimed at studying the effects of animated and interactive instruction on learning performance and subjective evaluation. The study was integrated as an actual session in a regular course on financial analysis, so that the results can be expected to be as ecologically valid as possible given the experimental setting. The results showed no significant difference in the learning phase regarding the time spent to study the instructions, though the mode of interaction with the material was very different between groups. We expected that learners in the sequential non-interactive condition would take more time to read the instruction, and especially to re-inspect it, since they could not change the display order of the items. We did indeed observe this trend, but it did not reach statistical significance. Thus computer-controlled instruction display did not dramatically hinder students' search strategies.

Two application tasks followed the study phase. Application tasks aim at measuring the extent to which the learned procedures can be reproduced from memory. They assess the construction of a correct surface representation of the concepts conveyed in the instruction. The first test task concerned the computation of a financial indicator (WCN), according to the procedure given in the instructions. Learners in the sequential interactive condition needed significantly less time than learners in the sequential non-interactive condition to compute the indicator, but they performed worse though this difference was not statistically significant. The second application problem concerned the construction of a financial balance sheet from accounting items, as shown in the instructions. Learners in the two sequential conditions performed this task significantly faster and more accurately than learners in the static condition. To sum up, little can be concluded from the first test task because performance did not significantly differ between conditions and trends in performance were not in agreement with differences in time investment. In contrast, the results of the second test task reinforce the idea that using sequential display facilitates the construction of a mental representation of the learned concepts.

The test phase ended with four transfer questions. Transfer problems aim at measuring the extent to which the learned concepts and procedures are integrated in a "runnable" mental model (Mayer 1989), which can be correctly used in similar situations to draw inferences on what is going to happen and why. Results showed that the learners in the two sequential conditions performed significantly higher than learners in the static condition. This result reinforces the assumption that sequentially displaying information facilitates the construction of a runnable mental model from which inferences can be drawn to understand similar situations.

Finally, the subjective evaluation showed, surprisingly enough, that interactivity significantly decreased the perceived pedagogical value of the document. This result seems in contradiction with the "active learning model" which states that learners must be actively engaged in learning activities in order to improve motivation and learning outcomes. An alternative explanation is offered by cognitive load theory (Sweller & Chandler 1994). Discovery-based learning environments require learners to simultaneously handle the manipulation of the tool, the management of their learning strategies and the to-be-acquired knowledge, which often leads to cognitive overload. As Mayer *et al*. (2002) noticed, discovery-based learning environments can be beneficial for learning under the conditions that sufficient cognitive scaffolding is provided to students. The material used in this experiment was a multimedia document and not a simulation environment, but learners in the sequential interactive condition yet had to face more cognitively demanding instructional material. This could be the reason that students in the sequential interactive condition had a less positive attitude toward the instruction and tended to show lower performance than students in the sequential non-interactive condition. A second possible explanation is provided by Kettanurak *et al*. (2001): Novices in a domain can hardly efficiently manage their learning strategy because they do not have the knowledge required to have a meta-cognitive attitude. As in the Kettanurak *et al*. (2001) study, we observed that learners in the sequential interactive condition spent less time on the instructions than learners in the sequential non-interactive condition. This observation reinforces the idea that students in the interactive condition did not know in which order items ought to be activated, and how much time they should spend on a given instruction page.

A main assumption of this study was that sequentially displaying the elements of a multimedia explanatory document would facilitate learning. The results clearly supported this assumption, irrespective of the fact if the order was computer-controlled or user-controlled. Our first explanation was that sequential display was decreasing cognitive load since elements could be gradually processed and mentally integrated. Learners' performance in application and transfer tasks did not contradict this explanation, but the subjective evaluation data did not confirm it either. Our second explanation was that the display order would act as a processing guide, with information displayed sequentially in a meaningful order, just as a teacher draws a schema on the blackboard while explaining its elements. In that case, the sequential non-interactive condition, with a predefined order, should be more beneficial than the sequential interactive condition. Overall the results did not confirm this explanation, except for the performance on the manipulation task, in which learners in the sequential non-interactive condition could have just mimicked the display order. Sequential non-interactive display thus appears to be adequate when learning outcomes entail mimicking manipulation procedures, as in software demonstration.

In conclusion, we think there is strong evidence to consider dynamic features offered by computer environments as an effective tool to promote deep learning. Sequential display seems adequate to teach procedures that will be mimicked and to build runnable mental models. The case for interactivity is not yet clear: Though the sequential interactive display was as beneficial to learning as the computer-controlled display, learners' evaluation of the pedagogical value of the instruction was significantly lower in this condition than in the other two conditions. Further research is needed to assess whether this effect is due to cognitive overload in managing the tool, to inadequate learning strategies for acquisition of knowledge, or to actual interface features. An important challenge for the future of education is to identify the most effective combination of features offered by computer technologies and instructional strategies to promote the emergence of powerful learning environments.

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