



**UNIVERSITÉ
DE GENÈVE**

**FACULTÉ DE PSYCHOLOGIE
ET DES SCIENCES DE L'ÉDUCATION**

Learning from multimedia animations

Control, collaboration and mental models

Canevas de thèse en psychologie
Présenté par Cyril Rebetez

Avril 2007

Membres de la commission proposés

- Prof. Mireille Bétrancourt, Université de Genève
- Prof. Guido Gendolla, Université de Genève
- Prof. Peter Gerjets, IWM-KMRC, Tuebingen



TABLE DES MATIERES

SUMMARY	3
RESUME	4
THESIS GOALS	5
STATE OF THE ART	5
1.1. THEORIES ON MULTIMEDIA LEARNING	6
1.1.1. COGNITIVE THEORY OF MULTIMEDIA LEARNING	6
1.1.2. TEXT AND GRAPHIC INTEGRATION	6
1.1.3. IMPACT OF AVAILABLE COGNITIVE RESOURCES	7
1.2. ADVANTAGES AND DRAWBACK OF ANIMATED PICTURES	8
1.3. DELIVERY FACTORS CAN AFFECT THE PROCESSING OF MULTIMEDIA INFORMATION	9
1.3.1. CONTROL AND INTERACTIVITY	9
1.4. COLLABORATIVE LEARNING SETTING	10
RESEARCH QUESTIONS	12
EXPERIMENTAL PARADIGM	13
1.5. PARTICIPANTS:	13
1.6. FACTORS AND MEASUREMENTS	13
1.6.1. MEASUREMENTS	14
1.7. MATERIALS	14
1.8. PROCEDURE	15
RESEARCH PLAN	16
1.9. EXPERIMENT 1	16
1.9.1. METHOD	16
1.9.2. HYPOTHESES	17
1.9.3. MAIN RESULTS	17
1.9.4. DISCUSSION	18
1.10. EXPERIMENT 2	18
1.10.1. JUSTIFICATION AND METHOD	18
1.10.2. HYPOTHESES	19
1.10.3. MAIN RESULTS	19
1.10.4. DISCUSSION	19
1.11. EXPERIMENT 3	19
1.11.1. JUSTIFICATION AND METHOD	19
1.11.2. HYPOTHESES	20
1.11.3. MAIN RESULTS	20
1.11.4. DISCUSSION	21
1.12. EXPERIMENT 4	21
1.12.1. JUSTIFICATION AND METHOD	21
1.12.2. HYPOTHESES	22
1.12.3. MAIN RESULTS	22
1.12.4. DISCUSSION	22
1.13. EXPERIMENT 5 (PROJECT)	23
1.13.1. JUSTIFICATION AND METHOD	23
1.13.2. HYPOTHESES	23
ETHICS	23
REFERENCES	24

Summary

Animated pictures and multimedia environments are proliferating. Their use and adequacy for learning and comprehension objectives seem obvious. The dynamic nature of animations offers unique opportunities to represent dynamic systems but its transitivity challenges the limited cognitive resources of learners which are novice in the domain. However, we still know little of the way dynamic, interactive and multimodal information sources are cognitively processed and integrated in a learner's mental model.

In the literature, the understanding of the processing of animated pictures is based on models of text and picture integration (Schnotz & Bannert, 2003) and multimodal information processing (Mayer, 2001). However, research still failed to clearly establish the advantage of animated pictures over static ones for learning purposes (Bétrancourt, Bauer-Morrison, & Tversky, 2001). The higher complexity of processing of multimedia materials, associated with time demands and low previous knowledge raises the cognitive demand very high.

Animations are also often used in computer-supported collaborative learning settings. In these specific settings, the cognitive demand might be even higher in terms of cognitive load (Sweller, van Merriënboer, & Paas, 1998). On the other hand the need for peers to use external representations to build a shared representation might be hindered by the transient nature of animation (Schnotz, Böckheler, & Grzondziel, 1999).

So far, 4 experiments have been carried out in order to investigate how cognitive processes involved in the processing of multimedia materials are influenced by the way these materials are presented and are used by the learner. Among the experimental conditions, we used snapshots of previous steps of the animation in order to reduce the real-time cognitive demand of animated materials. Our results were opposed to our hypothesis of a better grounding possibility for the peers with the help of these snapshots. Instead, we observed that individual learners obtained better learning results with snapshots, but collaborative learners obtained better results without snapshots than with them. We interpreted this result as a division of the available resources between the interaction with the computer and with the peer, hindering effective integration in the mental model. Further experiments investigated this effect by adding levels of control over the pace and content of the multimedia material. For our last experiment, we will manipulate two ways to recover and reprocess previous dynamic information, the level of control and the presence of snapshots.

Résumé

Les animations et environnements multimédia sont de plus en plus présents et leur utilisation pour des objectifs d'apprentissage semble évidente. La nature dynamique des animations offre un excellent moyen de représentation de systèmes dynamiques. Toutefois, leur fugacité rend difficile leur traitement en temps réel par des apprenants novices dans le domaine, en raison de ressources cognitives limitées. Néanmoins notre connaissance des processus cognitifs impliqués dans le traitement et l'intégration dans un modèle mental d'informations dynamiques, interactives et multimodales reste peu détaillée.

La littérature décrit ce phénomène sur la base de modèles d'intégration texte-image (Schnotz & Bannert, 2003), ainsi que de traitement d'information multimodale (Mayer, 2001). Néanmoins, les recherches peinent à démontrer l'avantage des animations sur des représentations statiques (Bétrancourt et al., 2001). La complexité de traitement des matériels multimédia, associée à une demande temporelle élevée et un niveau de connaissance basse dans le domaine fait certainement monter le niveau de demande cognitive trop haut.

L'utilisation d'animations est également présente dans le domaine de l'apprentissage collaboratif assisté par ordinateur. Dans ces conditions, la demande sur l'apprenant peut être encore augmentée en termes de charge cognitive (Sweller et al., 1998). Cependant, les pairs ont besoin d'utiliser des représentations externes afin de construire et maintenir une représentation partagée tout au long de l'apprentissage (Schnotz et al., 1999). Ce « grounding » pourrait être altéré par la nature transitive des animations.

Jusqu'ici, 4 expériences ont été réalisées afin de décrire certains des processus cognitifs en jeu dans ce type d'apprentissage. Parmi les conditions expérimentales, nous avons présenté à l'écran des images des étapes passées de l'animation afin de réduire la demande de traitement et d'intégration en temps réel. A l'inverse de notre hypothèse, les résultats montrent que les apprenants individuels ont mieux compris le phénomène avec les images supplémentaires que sans elles. Mais surtout, les apprenants en dyade ont obtenu des scores plus faibles avec les images que sans elles. Notre interprétation est une division des ressources entre l'interaction avec l'ordinateur et l'interaction avec le partenaire, gênant ainsi la construction du modèle mental. Les expériences suivantes ont tenté de vérifier cet effet en ajoutant des niveaux de contrôle et d'interaction sur le déroulement et le contenu de l'animation. Pour notre prochaine expérience, nous proposons de manipuler deux moyens de récupérer et re-traiter l'information d'une animation : le niveau de contrôle et la présence d'images supplémentaires.

Thesis goals

The fundamental objective of this thesis is to investigate the way humans process multimedia information, build an integrated representation from it and are able to use their updated mental models in further situations. The high cognitive demands and complexity of such representations imply very different cognitive processes to work together. Which processes are involved, to what extent, and how users and learners adapt to such demanding situations are very important questions for this field of study, and for this research.

A subsidiary and practical goal of this thesis is to define ways and guidelines for instructional designers to take benefit of the advantages of animated pictures with as few drawbacks as possible.

In order to achieve this, we will focus on two aspects. First, the effective design of the material itself, how features of the animation can be put in place to improve the animation's benefits. Second, the learning situation, such as a collaborative setting, how the context in which the material is used will improve its value and reveal its potential.

State of the art

Research on animated pictures mostly emerged from the field of text and pictures integration. In our research field, the term "multimedia" refers to a simultaneous presentation of words (printed or spoken) and pictures (photographic or schematic, static or dynamic) (Mayer, 2005). Thus, the research on multimedia learning and comprehension ranges from the integration of printed text and pictures (Mandl & Levin, 1989) to hypermedia and interactive virtual simulations (Rieber, 2005). The aim of this body of research is the effective construction of a mental model, from elements selection and comprehension to their integration with previous knowledge (Johnson-Laird, 1983). The multimedia capabilities quickly made animated pictures an appealing and efficient way to present information or to explain a phenomenon. Nevertheless, numerous types of presentations can be called animation and the definition itself is very broad (Bétrancourt & Tversky, 2000). In this work, we consider only explanatory dynamic depictions, not illustrative transition effects (blending, texts moving on the screen, powerpoint effects, etc.). We are interested in the processing of complex stimuli, based on how they are perceptually presented and how they can be interacted with. We will not integrate elements of pedagogical methodology and didactics in our research.

1.1. Theories on multimedia learning

A large body of research demonstrated that graphic depictions are beneficial to learning. One of the main explanations is provided by the mental model theoretical framework: Understanding a text requires the reader to form a mental representation, structurally analogical to the situation described (Van Dijk & Kintsch, 1983). Knowledge acquisition is done through the integration of organised new information in previous representations of the learner, called mental models (Johnson-Laird, 1983). Mayer (2001) but also Schnotz and Bannert (2003) developed models of how these mental models are created when interacting with a multimodal presentation.

1.1.1. Cognitive theory of multimedia learning

One of the most widespread theories of multimedia learning is described by Mayer (2001). This model is based on Baddeley & Hitch (1974) multi-component model of working memory. In particular, they showed that phonological and visuo-spatial information are stored in short-term memory by different processes with different resources. The dual coding theory formulated by Pavio (1986) also supports the separated processing of verbal and non-verbal (or visual) information. Hence, a word encoded in a verbal way will be better recalled if also encoded in a visual form. Mayer also describes a principle of active information processing (Mayer, 1999), stating that learning is more efficient if reinforced by actual cognitive investment and work. A conscious activity from the learner, such as voluntary attention shifts to important elements or mental organization. In the end, Mayer's theory of multimedia learning is close from Atkinson & Shiffrin (1968) model, with three phases of information processing: selection, organisation and integration to a prior mental model. Mayer (2003) insists on the fact that these phases are not a fixed order, but more an iterative process.

1.1.2. Text and graphic integration

Schnotz and Bannert's (2003) based their model on text comprehension, they described how verbal-symbolic and depictive information are conjointly and interactively processed in order to form a mental model, which eventually may affect conceptual organization. A propositional representation organizes semantic elements, in a symbolic structure. And a mental model is formed from visual and analogical organisation of the different elements. Both representations are strongly related and have similar structures.

The selection of pertinent information uses top-down processing. Previous knowledge guides the gathering of information. In the absence of a pertinent mental model to guide visual

exploration, other selection processes will be used. Lowe (2003; 2004) showed that learners novices in the domain were mostly relying on perceptive salience to extract information from a meteorological map, leading them to creating erroneous representations.

Knowledge organisation is both based on bottom-up and top-down processing. Perceptive organisation of the elements, as well as previous knowledge, is used in order to build a mental model linked with a propositional representation. These selective and organisational functions stand on working memory.

The main difference between Mayer's cognitive theory of multimedia learning and Schnotz's text and graphic integration model, apart their field roots, is their focus. Mayer describes a multiple memory system and a multimodal information processing. It focuses on the channels the information has to go through before being integrated in long term memory. Schnotz's model focuses on the transformations and organisation of information during its integration with previous mental models. Recently, Schnotz (2005) augmented his model with elements from Mayer's Cognitive theory of multimedia learning by integrating concepts of multiple memory systems (Atkinson & Shiffrin, 1968; Baddeley, 1986).

1.1.3. Impact of available cognitive resources

The human working memory resources are limited. Too much information to process means the loss of, at least, a part of it (Baddeley, 1986). Since animated pictures induce higher needs to process the information than static graphics, it is plausible that learners studying animation might experience a cognitive overload. This limitation is far less important for learners with previous knowledge in the domain since the presence of schemas in long term memory improves the limitations of the working memory (Ericsson & Kintsch, 1995).

However, the cognitive load model is often used to explain different experimental results when learning from animated pictures (Paas, Renkl, & Sweller, 2004; Sweller, 2003; Sweller, Chandler, Tierney, & Cooper, 1990). In this model, the authors distinguish three sources of cognitive load: The *intrinsic* cognitive load corresponds to the difficulty of a specific concept to be learned. It increases with the number and complexity of elements and relations. The *germane* cognitive load is generated by cognitive processes involved in the learning activity. Resources used for comprehension and organisation of every element in order to build the mental model are part of this source and necessary for the learning efficiency. The third source is called *extraneous* load. It gathers all additional cognitive processes not directly useful to learning. A deficient material, wrongly organised or incomplete, will firstly need to

be reorganised by the learner, in order to be understood and learned. Such supplementary processing requires some of the already limited cognitive resources. If the remaining cognitive resources are insufficient for the schema to be elaborated in long term memory, the learning process can be strongly impaired.

1.2. *Advantages and drawback of animated pictures*

Being more sophisticated than plain text or static images, animated graphics are often seen as evident improvement to explain or teach, especially dynamic concepts like a mechanical system or meteorological phenomena. Research by Thompson and Riding (1990) supports the hypothesis that animation facilitates learning since it presents the micro-steps of processes that are absent from static graphics. They used three versions of materials to teach the Pythagorean Theorem to children through a spatial demonstration. The first group saw a static graphic, the second a discrete animation (constituted of two static graphics) and the third a continuous animation. The third group outperformed the two others in term of comprehension. The authors stated that the third material contained more information since it depicted the micro-steps of the process. Schnotz, Böckheler and Grondziel (1999) worked with an interactive animation in order to teach time zones. In the first research presented, students using these animated materials obtained better detail encoding scores than the ones using static pictures. Nevertheless, no difference was found on mental simulation task.

Research on animated pictures often failed to find strong benefits of this medium, even when the instructional animation was carefully designed (Bétrancourt & Tversky, 2000; Lowe, 1999). For example, Opfermann, Gerjets, & Scheiter (2006) used an hypermedia environment to teach probabilities but their conditions using animation did not improve comprehension performance as compared with conditions using static presentations.

When learners are presented with static graphics, they have to mentally animate the presented information in order to understand the dynamism of the phenomenon. Dynamic graphics disambiguate the exact process of change by explicitly showing every transition point (micro-steps) between the main steps. Though, presenting changes over time has the major inconvenient of changing over time! Indeed, the informational flow induced by the presentation makes all pictorial information transient. Information comes and goes with every frame. There is no perceptive way to get it back when it is gone. Static pictures do not have this additional time-related information but allow learners to quietly explore them and to integrate elements in their mental model.

Schnotz and Rasch (2005) develop the idea of three possible effects of animated pictures on the learner. The first is a “facilitating” effect. Animation can facilitate the construction of a dynamic mental model, mainly by explicitly showing the micro-steps. The second, called “enabling” effect, goes further: Animated graphics could make possible the comprehension of specific dynamic processes, very hard to apprehend from static pictures for example. Very complex processes have to be seen in action to be understood. The third effect, negative to learning, is called “inhibiting effect”. Animated pictures could inhibit the learner to mentally animate the dynamic phenomenon. The result would be the illusion of comprehension and the poorer mental model described by Lowe (2003; 2004).

Processing a multimedia presentation and integrating its elements in a mental model is a very demanding task for learners who are novices in the domain. Especially since they can not rely on top-down selection and organisational processes from an existing mental model, this contributes to overflow their cognitive resources. Helping these learners is crucial but understanding how and why specific ways to handle the information change the cognitive processes involved is even more crucial.

1.3. *Delivery factors can affect the processing of multimedia information*

1.3.1. *Control and interactivity*

One simple way to enable learners to process all information and at the same time foster their cognitive engagement with the presentation is to give them control over the pace of the animation. Mayer & Chandler (2001) investigated a very minimalist control device which consisted in breaking down the animation in short sequences. A pause was automatically included after each animated sequence and the learner had control to run the next sequence. The results showed that learners who studied the controlled animation had better transfer performance than learners who studied the continuous animation. The authors interpreted their results in terms of cognitive load, since the pauses allowed learners to integrate partial information before processing further, and thus save resources in working memory. Using a more advanced control panel, Schwan & Riempp (2004) showed that users who had control over the pace and direction of videos learned more rapidly how to tie nautical knots than learners who could not act on the video. The authors claimed that the learners with control could choose the parts on which they wish to allocate more attention and thus distributed their cognitive resources more effectively. Both studies show positive effects for learning when

using a controlled animation. However, Bétrancourt & Realini (2005) used three different levels of control of an animation: without control, partial (only pause/play), or full control (also back and forward). Participants had 10 minutes, three times the total duration of the animation, to study it at their own pace, using the available controls. Results showed no difference of the level of control on retention questions. But participants using no control had higher inference scores than the other groups. It was also observed that participants with a scientific background obtained higher results with a low level of control, as opposed to participants who studied arts and humanities which obtained higher results without any control. The main contradictory result was explained by the possible creation of a split-attention effect by the control panel (Sweller et al., 1998). But this does not explain why other studies involving control did not have this problem. Wouters, Paas & Van Merriënboer (2005) compared the effects of control on the pace of the presentation (by the learner or the computer) and of the segmentation of the presentation (step-by-step or continuous) when presenting an expert-model. Results showed that participants with a continuous presentation but able to pace it themselves obtained the best far transfer scores. Schneider & Boucheix (2006) presented their participants with a technical material of a pulley system in three different control conditions (none, five animated steps, fully controllable). Although participants' visual exploration varied, no effect of the control condition was observed on the comprehension test. Similarly, the controllable materials from Opfermann et al. (2006) were rarely used by participants and did not lead to a better comprehension of the material.

If benefits of control seem obvious concerning multimedia learning, not enough studies put it into practice and the actual results show an unexpected pattern. Giving the learner more tools and control might not be the best solution for an optimal processing and integration.

1.4. Collaborative learning setting

The question of collaboration has been studied from several perspectives. Its importance in terms of process of negotiation and argumentation led to the theories of socio-cognitive conflict (Doise & Mugny, 1984). According to the distributed cognition theory (Hutchins, 1995), learning can be improved when the processing complexity is distributed over several cognitive systems, for example by using collaborative learning situations. In this work we focus less on the process of collaboration but more on the situation and the benefits it can bring it terms of information processing. To this end, the computer-supported collaborative learning (CSCL) field defines the effectiveness of collaborative learning through participants'

efforts to integrate their different perspectives (Perret-Clermont, 1993; Roschelle & Teasley, 1995). Learners have to negotiate meanings, share and compare their points of view and construct common knowledge.

An important point for collaborative learning is the necessity for co-learners to build a shared representation of the task and of the different elements linked to it. This common ground has to be maintained all along the task, by a process called “grounding” (Clark & Brennan, 1991; Roschelle & Teasley, 1995). Schwartz (1995) stated that what produces learning is the “effort after shared meaning”. Through this process, participants verify their mutual comprehension of the problem. Similarly, Dillenbourg (1999) claimed that the benefit of collaboration for learning is a ‘side-effect’ due to elaborating and maintaining a shared representation of the problem at hand. The grounding can be processed through “artefacts”, real-world objects which are used as symbols or information source to create an array of accessible knowledge around an individual (Moore & Rocklin, 1998). These same artefacts can be used to mediate and communicate the same knowledge with others (Stahl, 2002).

According to collaborative learning theories, facilitating the grounding process would facilitate communication and thus grounding would induce better learning results. On the other side, as dynamic graphics are transient by nature, collaborative learners would have a harder time to refer to objects which are not on the screen anymore. This argument could explain one result of Schnotz, Böckheler and Grondziel (1999). Participants were asked to explore an interactive material in order to understand time zones. In their first experiment, participants learning individually obtained better detail encoding results when learning from a dynamic material than from a static one. In the second experiment, participants in collaborative learning setting, showed lower learning results while learning from a dynamic material than from a static material (for both detail encoding and mental simulation tasks). The authors explained these opposite findings as an augmentation of extraneous cognitive load. The reason being that collaboration requests cognitive resources in order to be maintained, making it harder for participants to involve resources in the processing of a dynamic and interactive presentation. Learners would have to do a lot of communication, not directly related to comprehension. We believe that a lack of permanent references, or artefacts, for the pairs would force collaborative learners to constantly contextualise their discourse, hindering their actual processing of information. Providing an efficient tool to help the pairs in their grounding activities would then be helpful to them.

Dillenbourg & Bétrancourt (2006) defined the “collaboration load” as the supplementary cognitive processes involved with collaboration (division of labour, verbalization, grounding, mutual modelling). These processes need cognitive resources but also facilitate the learning process. However, like for Schnotz, Böckheler and Grondziel (1999), the collaboration load costs added to a dynamic presentation can induce too much supplementary processing to allow an efficient comprehension and the creation of a “runnable” mental model (Mayer, 1989). Collaborative setting can improve learning since each learner can act as an external memory and an assessment reference for the other learners. The contrary could also be claimed since learners working collaboratively should allocate cognitive resources to elaborate a shared understanding of the situation and distributed cognition (Clark & Brennan, 1991; Roschelle & Teasley, 1995) and to maintain a shared representation of the problem (Dillenbourg, 1999). This allocation of cognitive resources in the collaboration process is positive when optimal, but negative when not enough cognitive processes are triggered or when the collaboration requirements take too much resources (Dillenbourg & Bétrancourt, 2006).

Research questions

The current research on multimedia learning underlines the complexity of the learning processes when applied to several and transient sources of information. In order to understand how the different cognitive processes are working together in this context, we aim to design features of multimedia presentation which have an effect on the way information is processed and on the resulting understanding of the depicted phenomenon.

The first factor we propose to investigate is the level of control over the animation. This feature is broadly present in educational multimedia but its real benefits or drawbacks are unclear. Letting the learner control the pace of the animation should obviously benefit. However, a learner with no previous knowledge of the domain will be unaware of the important depictions and concepts, will he be able to stop at the right times in order to integrate the elements together and with earlier mental models? As showed by Lowe (2003; 2004) novice learners focus on perceptually salient elements, not integrating the conceptually important ones. Others features of dynamic instructional materials can also be of importance in order to take the most of the advantages of dynamic pictures while limiting the drawbacks.

Additional processing of information is another way to increase the efficacy of animated pictures. Verbalization and self explanation will be investigated but the focus will be made on

collaborative learning situations. Before this work, only Schnotz et al. (1999) studied the effect of collaborative learning setting when learning from an interactive multimedia material. The additional processing involved with such settings will be revelatory of the potential of animated pictures; such activities could even enable the benefits of multimedia learning.

Experimental paradigm

We present here the general methodology used in our experiments: participants and their enrolment, the several factors used, as well as the measurements. Three instructional materials were developed for this experiment and they are also described here, along with the general experimental procedure. In the next part, specifics of the experiments (with a more specific description of the factors) will be presented along with a short selection of results.

1.5. *Participants:*

For all the experiments the chosen population consisted in students from several faculties of the University of Geneva. Most of the participants studied in the field of human and social sciences. However, due to collaboration with Lausanne’s institute of technology, half the participants of the first experiment were students there. Participants were men and women between 18 and 40. For experiment 1 and 3, participants received respectively CHF 20 and CHF 10 for their time and involvement.

1.6. *Factors and measurements*

Across the different experiments, several factors are used in conjunction with each other; table 1 presents a summary of their appearance in the several experiments. Factors and measurements will be presented in detail in the context of the specific experiments.

Table 1: summary of the experiments				
N°	Date	N	Factors (nb of modalities)	Experimental Materials
1	Spring 2004	160	Type of presentation (2) Snapshots of previous steps (2) Learning setting (2)	Astronomy + Geology
2	Spring 2005	40	Verbalization level (4)	Astronomy + Geology
3	Summer 2005	80	Control over the material (2) Learning setting (2)	Geology
4	Summer 2006	113	Control (+ “simulation”) (3) Learning setting (2)	Additive/subtractive lights
5	In preparation Summer 2007	40	<i>Control over the animation</i> (2) <i>Snapshots of previous steps</i> (2)	<i>Geology</i> <i>(with eye tracking data)</i>

1.6.1. Measurements

In all experiments a post-test was developed in order to assess the level of comprehension reached by the participants. Multiple choice questionnaires were used, assessing retention (remembering facts and definitions from the presentation) and comprehension aspects (inference, understanding the underlying rules and interactions and inferring new ones).

Subjective scales were also developed and improved as the experiment progressed. At first inspired from the nasa-tlx scales to assess the workload of a task (Hart & Staveland, 1988), they evolved to several aspects of the learning activity (effort invested, task demand, interaction demand, activity level, material efficacy, perceived stimulation). Moreover, duration of the learning phase was measured (in the experiments where it was not controlled), as well as the time needed to answer the post-test questions.

The interactions with the materials and with the peer were also observed, firstly through screen captures of all the learners, plus video taping of the participants in group of two. Secondly, specific interactions such as number of use of controls and viewed parts were recorded in log files for an easier analysis. In order to improve this aspect, the use of eye movements recording is scheduled for experiment 5.

Concerning the assessment of individual cognitive skills, classic standardized tests were used, a computerized version of the Corsi blocks (Milner, 1971), of the paper-folding test (Ekstorm, French, Harman, & Dermen, 1976), and the similarity test from the WAIS-R intelligence scale (Wechsler, 1981).

1.7. Materials

So far, three different materials have been developed and used in our experiments. The first and most used one explained the geological phenomenon of rift and subduction. It was developed using Macromedia Flash® and involved an audio explanation. The dynamic version was 3.32 minutes long and was subdivided in twelve sequences according to instructional units. The static version used in experiment 1 presented only 12 pictures taken from the dynamic version (the last frame of each part). This material was used in experiment 1, 2 and 3 and will be used in experiment 5.

Of similar structure, the second material presented the astronomical phenomenon of Venus transit and its observation conditions. It was designed using VRML (virtual reality modelling language). As for the first material, the snapshots used in the permanence condition with these

materials were the same images as the ones used in the static condition (the last frame of each sequence). This material was used in experiment 1 and 2.

The third material was different since we designed it in order to implement a “simulation” condition of control. Thus, direct manipulation of the content had to be possible. Designed using Macromedia Authorware®, this material explained the additive and subtractive synthesis of colours. It was constituted of nine steps, each displaying one multiple-choice question along with a graphic visualization. Participants in the simulation condition could directly manipulate the colours proportion in the device while participants in the animation conditions watched animations presenting the diverse possible colour adjustments. This material was used in experiment 4.

1.8. Procedure

The general design is a between-subject experimental plan. All participants are randomly assigned to an experimental condition and start with signing a consent form describing the general goals of the experiment, what was expected of them, that all personal data would be confidential and that they could leave at any time. Participants in collaborative learning setting were also informed of the further video recording of their activities.

All experiments start with a short knowledge test on the domain used in the material (geology, astronomy or colour composition). Participants with good scores at these tests are then removed from our samples. After that, participants read a small introduction to the phenomenon and are invited to study the material corresponding to their experimental condition. Between the sequences, participants are asked to “explain the changes to themselves”. In the collaborative learning setting, two participants study the material together. Once the learning session is finished, participants are asked to individually answer the subjective scales and potential cognitive test before answering the post test.

Research plan

Five experiments are planned; the first four have already been completed, although some data analyses are still scheduled. The last experiment is considered for the end of the academic year. In order to keep this project short, we decided to focus the presentation of results only on learning performance measures. The funding of experiments 1 to 3 was made possible through a NSF grant (#11-68102-02) between October 2003 and March 2006, in collaboration with Prof. Pierre Dillenbourg and Mirweis Sangin (EPFL, Lausanne). Figure 1 presents the timeline of this thesis work, the final manuscript is expected in the second part of 2008.

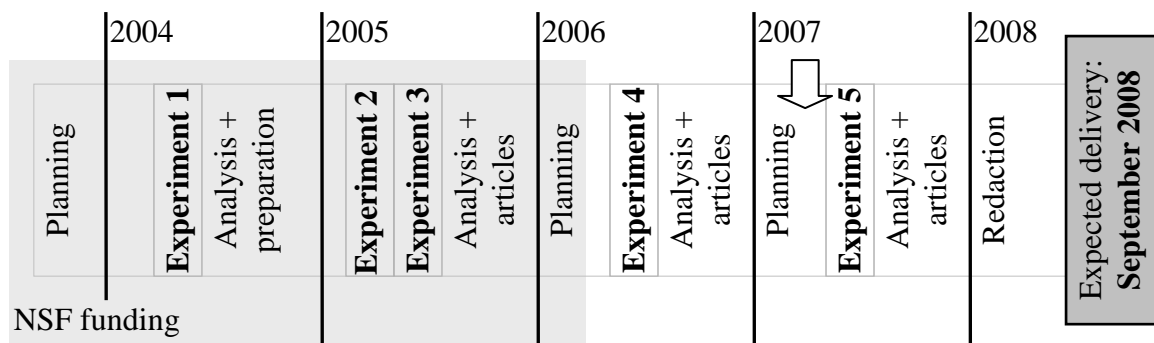


Figure 1 : Experiments sequence and planification

1.9. Experiment 1

1.9.1. Method

In spring 2004, 160 participants were distributed depending on three factors in an inter-subject experimental design (8 groups): Type of presentation (static/dynamic), the learning material was manipulated either to be animated or static. Participants in the dynamic condition studied animated pictures and participants in the static condition studied static pictures (the key pictures from the dynamic version were used). The same audio explanations were used for both versions of the material.

Snapshots (with/without), in this second condition, snapshots of the previous steps of the learning material were available to half the participants. The second half of learners had no snapshots and thus had no way to consult pictures from the previous steps of the material.

The last factor was called the learning setting (individual/collaborative). The way participants had to study the instructional materials and process the information is manipulated through individual or collaborative settings. Participants learning individually are alone during the

whole experiment. In collaborative learning setting, participants study the materials in pairs and have to talk about it. All the tests and scales are answered individually.

Two experimental materials were used (geological and astronomical). And participants were assessed through retention and inference tests (32 questions), cognitive tests (Corsi blocs and Paper folding tests) and task load scales (from nasa-tlx). In this paper we will not present the results from the scales and cognitive tests.

1.9.2. Hypotheses

The actual depiction of transition between steps is needed in order to create a fully runnable mental model and not only create partial representations. Accordingly, (1) we expect higher retention and inference scores with the dynamic presentation than with the static one. (2) The presence of snapshots will also improve these scores since novice learners have a chance to recuperate and process missed depictive elements of the presentation. (3) We do not expect a main effect of the learning setting but an interaction between the learning setting and the presence of snapshots since those snapshots will provide pairs with an effective way to achieve grounding, thus allowing them to build and maintain shared representations. (4) Consequently, pairs will benefit even more from snapshots than individual learners and permanence snapshots would also benefit more to participants in dynamic condition than in static condition since it would lower the drawback of fugacious information.

1.9.3. Main results

Our first hypothesis was comforted since the type of presentation had a significant effect both on retention ($F(1,152) = 9.2$; $p < .01$) and inference scores ($F(1,152) = 6.3$; $p < .05$), participants using dynamic graphics obtained higher score than participants using static pictures. As we expected in our third hypothesis, participants learning in group of two did not achieve overall higher scores than individual learners ($F(1,152) = .3$; ns). A significant interaction was observed between the type of presentation and the learning setting on the inference score ($F(1,152) = 7.6$; $p < .01$). Participants in collaborative setting obtained better results when using dynamic presentations than static ones ($F(1,76) = 15.1$; $p < .01$). Individual learners obtained similar results with both types of presentation.

An interaction was also significant between learning setting and the presence of snapshots on the inference score ($F(1,152) = 6.6$; $p < .05$). Participants learning in pairs obtained higher scores without permanence than with the snapshots ($F(1,76) = 4.0$; $p < .05$), but the trend is reversed for individual learners. In our fourth hypothesis, we expected an interaction but not

this result; accordingly, this hypothesis can not be accepted. Our second hypothesis can not be accepted either since no main effect of the presence of snapshots was observed ($F(1,152) = .01; ns$). Various effects were observed on the subjective scales but will not be discussed further in this document.

1.9.4. Discussion

The complex results obtained in this experiment contributed to show that dynamic pictures alone, even efficiently designed, do not guarantee better learning results. An external help, such as collaborative learning setting proved efficient to take advantage of the potential of this medium. However the interaction observed between learning setting and information permanence was unexpected. With the help of verbal and gesture interactions analysis we interpreted this result as interferences in the collaboration process due to the interaction with the screen (the snapshots). Referring to the split-attention effect (Sweller & Chandler, 1994), we called this phenomenon a “split-interaction effect”.

Several parts of results and conclusions of this experiment were shared in conferences (Rebetez, Betrancourt, Sangin, & Dillenbourg, 2005; Sangin, Molinari, Dillenbourg, Rebetez, & Betrancourt, 2006), and are expected to be published in scientific journals (Rebetez, Sangin, Betrancourt, & Dillenbourg, in review; Sangin, Rebetez, Dillenbourg, & Betrancourt, submitted).

1.10. Experiment 2

1.10.1. Justification and method

In experiment 1, the observed effect of the learning setting when learning from dynamic pictures was very strong. However, the positive effect of collaborative settings could be explained by the verbalization involved in the collaborative learning situation.

During the beginning of the summer semester 2005, 40 students participated and studied the same materials as in experiment 1 (geology and astronomy), with the same procedure, in a between-subject plan. The verbalization level factor was designed to affect the way participants would process the information from the learning materials (control, verbalization, self explanation or explain to other). Between steps of the instructional material, participants were asked to “explain themselves the changes involved”. The control group received no more specific instruction. The verbalisation group was asked to do this explanation while speaking aloud. The self-explanation group received a special instruction in order to improve elaboration and processing (Chi, 2000). The last group was asked not to elaborate for

themselves but as if they had to explain what happened in the material to another participant. All participants studied dynamic pictures in individual learning condition. Paper folding and Similarity tests were also answered by the participants.

1.10.2. Hypotheses

Inspired by Ploetzner et al. (1999), we expect the verbalization condition to provide no better understanding of the depicted phenomenon than the control condition. However, based on Chi (2000), we expect the participants asked to self-explain or to explain to other to obtain slightly better results in retention and inference questionnaires but not as high as the participants in collaborative setting in experiment 1.

1.10.3. Main results

A significant effect of the verbalization factor was observed ($F(3,36) = 3.9$; $p < .05$). However, the highest performances were obtained by the control group (significantly higher than the “verbalization” and “explain to other” groups). Of course the time taken to study the material was also longer for participants having to self explain or to explain to other than participants in control or verbalization groups ($F(3,36) = 8.1$; $p < .05$).

1.10.4. Discussion

This control experiment allowed us to refute an effect of verbalization or of self-explanation to explain the results of experiment 1. Moreover, this result strengthens the hypothesis of Dillenbourg (1999). Like Ploetzner et al. (1999), we did not show that the learning effects of collaboration are due to processes activated through collaboration but we showed that verbalization in itself is not to be taken into account in our setting. Moreover the impairing effects of the self-explanation condition is very similar to the results provided by Gerjets, Scheiter & Cartambone (2006).

1.11. Experiment 3

1.11.1. Justification and method

In the results of experiment 1, the interaction between the snapshots and the learning setting was not expected this way. We observed that the snapshots were helping individual learners but hindering collaborative learners. As discussed in experiment 1, we defined a split-interaction hypothesis and we decided to verify this hypothesis by integrating more interaction opportunities with the device while maintaining the learning setting factor.

During the end of spring 2005, 80 students were recruited and assigned to one of our four experimental conditions, depending on two independent variables: control over the material (high/low). Using animated pictures, different levels of control were available over the presentation. With a low level of control, participants could not act over the pace of the presentation. Between each of the twelve steps, they had to press on a button to see the next part, and this was their only interaction with the device. With a high level of control, participants could stop the animation at other times than between the steps, but also move forward and backward in order to see a specific moment or process.

The second independent variable was the learning setting (individual/collaborative), described in detail in experiment 1. For this experiment, only the dynamic version of the geological material was used. Participants had 10 minutes and 33 seconds to study the animation and could not leave before that time was over (they had time to watch the animation three times).

1.11.2. Hypotheses

Since the pacing of the presentation allows the learner to match the informational flow to his level of comprehension, (1) we expect better retention and inference results for participants with high control than participants with low control. As in experiment 1, (2) we expect no main effect of the learning setting on retention and inference scores. In order to confirm the split-interaction observed in experiment 1, we expect an interaction between the two factors. (3) Participants in individual learning setting will be able to take benefit of a high control as compared to a low control. Inversely, participants in collaborative learning setting will see their collaborative process hindered by the interaction with the device; consequently they will obtain lower scores with high control than with a low level of control.

1.11.3. Main results

The interaction between our factors was significant concerning the retention score ($F(1,73) = 4.31$; $p < .05$). However, the results did not support our third hypothesis since participants in collaborative learning settings obtained higher scores with a high control than with a low control. The trend was inversed for participants in individual conditions. Participants in collaborative setting also answered the post-test quicker than participants in individual condition ($F(1,73) = 6.98$; $p < .01$). Our first hypothesis was not accepted since no effect of the level of control was significant on the learning score ($F(1,73) = .34$; *ns*). As we assumed, no effect of the learning setting was visible on the learning score ($F(1,73) = 3.2$; *ns*).

Several exploratory analyses were carried out in order to understand how participants used the controls and how this exploration impacted their understanding of the phenomenon. In particular, participants with a high level of control and exploring the material in a non-linear way obtained higher global scores than those exploring it in a linear way ($F(1,36) = 6.40$; $p < .05$).

1.11.4. Discussion

No split-interaction effect was present in these results, and this questions our “split-interaction” interpretation of the results of experiment 1. However, the collaborative learning settings were different from experiment 1 since the learning (and collaboration) time was limited in experiment 2 but not in experiment 1. Moreover, due to the nature of the level of control factor participants were able to see the animation several times, in experiment 1 the animation was seen only once. These differences may have flawed the collaboration process and changed the learning conditions. Results from this experiment were presented in two international conferences (Rebetz, Bétrancourt, Sangin, Dillenbourg, & Molinari, 2006a, 2006b).

1.12. Experiment 4

1.12.1. Justification and method

The contradictory results from experiment 1 and 3 persuaded us to vary even more the control modalities over the material. In a new condition called “simulation” participants had to interact directly with the presented content. In order to achieve this, a third instructional material was developed, teaching about additive and subtractive colour mixing.

In spring 2006, 113 students were assigned to one of our 5 experimental groups depending on two factors: the learning setting (individual/collaborative) described earlier and the level of control (animation low, animation high and simulation). In the “animation low” condition, participants could only study the presentation in a linear way, and play it again when it was finished. In the “animation high” condition, participants were able to stop the animation but also to move forward and backward in order to see a specific moment or process. The “simulation” condition was different, participants could interact directly with the presentation in order to modify its variables and study their effects on other parts of the system.

For practical reasons, and since our hypothesis mainly questioned the split-interaction effect, the group in collaborative setting and high control over the animation was not used. We planned a comparison of groups with low control or simulation, depending on the learning

setting to test our split-interaction hypothesis. We developed the condition with high control in individual learning setting in order to compare our three levels of control as a continuum.

1.12.2. Hypotheses

Firstly, we aim to check the interaction of the learning setting and the level of control (without the high control condition). (1) We expect a split-interaction effect; participants in individual condition will benefit more from the simulation condition than from the low control condition. Conversely, participants in collaborative settings will obtain better results with low control than in the simulation condition. (2) In individual learning setting, participants will obtain the higher comprehension scores in the simulation condition, and the lower ones in the low control condition.

1.12.3. Main results

An analysis of variance on the four main groups (without the group in individual learning settings and high control) showed no interaction on learning performances or answer times. Moreover, no main effect was visible depending on these factors. Consequently our first hypothesis can not be accepted. The second hypothesis is not accepted either, since the three control conditions in individual learning setting did not induce significantly different comprehension scores in our participants ($F(1,54) = .76; ns$). However, the time to learn the material was lower for participants in the simulation condition than in the other conditions ($F(3 ;51) = 3.26; p < .05$). On the subjective scales, the perceived activity ($F(1,54) = 13.92; p < .01$) and stimulation ($F(1,54) = 3.66; p < .05$) levels were higher for participants learning from the simulation than from the low control animation.

1.12.4. Discussion

If the effect induced by our experimental conditions was not significant on the learning performance, participants in the simulation group obtained similar results in less time than participants in the animation condition. The simulation condition was more efficient if not more effective for learning. This result is similar to Schwan & Riempp (2004), we can interpret this as a better management of available cognitive resources due to the simulation condition. Interactions and exploration behaviours are still under analysis in order to investigate whether learning results could be related to exploration behaviours for participants with control over the material. This experiment does not support our split-interaction hypothesis and a new interpretation of the results of experiment 1 is needed.

1.13. Experiment 5 (project)

1.13.1. Justification and method

Experiment 1 and 3 showed the importance of what learners do with the material to understand how they can take benefit of animated pictures. We plan to give us tools to analyse more deeply the interactions of the learners with the material. Moreover, since the use of controls alone does not give much information on the learner's attention and visual exploration, we plan to record their eye movements. Inspired by the results of experiment 3, we plan to go further in describing exploration patterns from learners. Different visual exploration patterns could lead to different levels of comprehension. The experimental factors are still under discussion. However, the level of control over the animation (low or high), presented in experiment 2 and the information permanence (with or without snapshots), presented in experiment 1 are our actual candidates. The rest of the method will be close to the one used in experiment 3. During the learning phase, their eye movements will be recorded through video cameras imbedded in the screen, allowing us to know at any time were participants looked at on the screen.

1.13.2. Hypotheses

Since the experimental factors are still under definition we will not define precise hypothesis. We plan to use the eye tracking data along with recordings of the screen and learner's interactions to support our findings during experiment 3. Exploration patterns such as linear versus non-linear exploration will be a start but the ocular data will allow us to go deeper in the definition of these patterns.

Ethics

In order to protect participant's confidentiality none of our files or document allows us to trace a specific result to a particular participant. Consent forms were signed before the experiment, they described the general goals of the experiment, what was expected of the participants, that all personal data would be confidential and that participants could leave at any time. Participants in collaborative learning setting were also informed of the further video recording of their activities. In the end of the experiment, the experimenter was open to discuss the goals and hypothesis of the experiment and proposed the participants to give their e-mail to receive a summary of results. The e-mails were stored with the consent forms and could not be associated with specific results or log files.

References

- Atkinson, R. C., & Shiffrin, R. M. (1968). Human memory: A proposed system and its control processes. In K. W. Spence & S. J. T. (Eds.), *The psychology of learning and motivation: advances in research and theory* (Vol. 2, pp. 89-195). New-York: Academy Press.
- Baddeley, A. D. (1986). *Working Memory*. Oxford: Clarendon Press.
- Baddeley, A. D., & Hitch, G. J. (1974). Working Memory. In G. A. Bower (Ed.), *Recent advances in learning and motivation* (Vol. 8, pp. 47-90). New York: Academic Press.
- Bétrancourt, M., Bauer-Morrison, J., & Tversky, B. (2001). Les animations sont-elles vraiment plus efficaces? *Revue d'intelligence artificielle*, 14(1-2), 149-166.
- Bétrancourt, M., & Realini, N. (2005). *Le contrôle sur le déroulement de l'animation*. Paper presented at the Journée d'Etude sur le Traitement Cognitif des Systèmes d'Information Complexes, JETCSIC'2005, Nice.
- Bétrancourt, M., & Tversky, B. (2000). Effect of computer animation on user's performance: a review. *Le travail humain*, 63(4), 311-330.
- Chi, M. T. H. (2000). Self-explaining expository texts: the dual processes of generating inferences. In R. Glaser (Ed.), *Advances in instructional psychology* (pp. 161-238). Mahwah: Erlbaum.
- Clark, H. H., & Brennan, S. A. (1991). Grounding in communication. In L. B. Resnick, J. M. Levine & S. Teasley (Eds.), *Perspectives on socially shared cognition*. Washington: APA Books.
- Dillenbourg, P. (1999). What do you mean by collaborative learning ? In P. Dillenbourg (Ed.), *Collaborative-learning: cognitive and conceptual approaches* (pp. 1-19). Oxford: Elsevier.
- Dillenbourg, P., & Bétrancourt, M. (2006). Collaboration Load. In J. Elen & R. E. Clark (Eds.), *Handling complexity in learning environments: research and theory*. Amsterdam: Elsevier.
- Doise, W., & Mugny, G. (1984). *The social development of the intellect*. Oxford: Pergamon Press.
- Ekstorm, R. B., French, J. W., Harman, H. H., & Dermen, D. (1976). *Manual for kit factor-referenced cognitive tests* (Educational testing services ed.). Princeton, New Jersey.
- Ericsson, K. A., & Kintsch, W. (1995). Long-term working memory. *Psychological Review*, 102, 211-245.
- Gerjets, P., Scheiter, K., & Catrambone, R. (2006). Can learning from molar and modular worked examples be enhanced by providing instructional explanations and prompting self-explanations ? *Learning and Instruction*, 16(2), 104-121.
- Hart, S. G., & Staveland, L. E. (1988). Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research. In P. A. Hancock & N. Meshkati (Eds.), *Human Mental Workload* (North Holland ed., Vol. 52, pp. 139-184). Amsterdam: Elsevier Science Publishers B. V.
- Hutchins, E. (1995). *Cognition in the wild*. Cambridge: MIT Press.
- Johnson-Laird, P. N. (1983). *Mental models: Towards a cognitive science of language, inference, and consciousness*. Cambridge: Harvard University Press.
- Lowe, R. K. (1999). Extracting information from an animation during complex visual learning. *European journal of psychology of education*, 14, 225-244.
- Lowe, R. K. (2003). Animation and learning: selective processing of information in dynamic graphics. *Learning and Instruction*, 13, 157-176.
- Lowe, R. K. (2004). Interrogation of a dynamic visualisation during learning. *Learning and Instruction*, 14, 257-274.
- Mandl, H., & Levin, R. (1989). *Knowledge acquisition from text and pictures*. Amsterdam: Noth holland.
- Mayer, R. E. (1989). Models for understanding. *Review of Educational Research*, 59(1), 43-64.
- Mayer, R. E. (1999). *The promise of educational psychology* (Vol. 58). Amsterdam: Noth Holland.
- Mayer, R. E. (2001). *Multimedia learning*. Cambridge: Cambridge University Press.
- Mayer, R. E. (2003). The promise of multimedia learning: using the same instructional design methods across different media. *Learning and Instruction*, 13, 125-139.
- Mayer, R. E. (2005). Introduction to multimedia learning. In R. E. Mayer (Ed.), *The Cambridge handbook of multimedia learning* (pp. 1-18). Cambridge: Cambridge university press.
- Mayer, R. E., & Chandler, P. (2001). When Learning is just a click away: does simple interaction foster deeper understanding of multimedia messages? *Journal of Educational Psychology*, 93(2), 390-397.
- Milner, B. (1971). Interhemispheric differences in the localization of psychological processes in man. *British Medical Bulletin*, 27, 272-277.
- Moore, J. L., & Rocklin, T. R. (1998). The distribution of distributed cognition: multiple interpretations and uses. *Educational Psychology Review*, 10(1), 97-113.
- Opfermann, M., Gerjets, P., & Scheiter, K. (2006). *Do multimedia principles apply to hypermedia? The moderating role of different levels of learner control for the validity of multimedia design principles*. Paper presented at the 2nd Joint Meeting of the EARLI SIG Instructional Design and SIG Learning with Computers, Leuven, Belgium.
- Paas, F., Renkl, A., & Sweller, J. (Eds.). (2004). *Advances in cognitive load theory: Methodology and instructional design [Special issue]* (Vol. 32).
- Pavio, A. (1986). *Mental representations: a dual coding approach*. New York: Oxford University Press.
- Perret-Clermont, A. N. (1993). What is it that develops? *Cognition and Instruction*, 11, 197-205.
- Ploetzner, R., Dillenbourg, P., Praier, M., & Traum, D. (1999). Learning by explaining to oneself and to others. In P. Dillenbourg (Ed.), *Collaborative-learning: Cognitive and Computational Approaches* (pp. 103-121). Oxford: Elsevier.
- Rebetz, C., Bétrancourt, M., Sangin, M., & Dillenbourg, P. (2005). *Collaborer pour mieux apprendre d'une animation*. Paper presented at the IHM 2005, Toulouse (France).

- Rebetez, C., Bétrancourt, M., Sangin, M., Dillenbourg, P., & Molinari, G. (2006a). Handling complexity in multimedia learning: effects of control and collaboration when studying animation. In G. Clarebout & J. Elen (Eds.), *Earli SIG Conference: Instructional design & Learning and instruction with computers*. Leuven: Sense Publishers.
- Rebetez, C., Bétrancourt, M., Sangin, M., Dillenbourg, P., & Molinari, G. (2006b). *Learning from dynamic visualizations: Decreasing cognitive load and promoting learning?* Paper presented at the Earli SIG Conference: Text and Picture Comprehension, Nottingham.
- Rebetez, C., Sangin, M., Betrancourt, M., & Dillenbourg, P. (in review). Learning from animation enabled by collaboration. In P. Gerjets & K. Scheiter (Eds.), *Cognitive and socio-motivational aspects in learning from dynamic visualizations, Special Issue of Instructional Science*.
- Rieber, L. P. (2005). Multimedia learning in games, simulations and microworlds. In R. E. Mayer (Ed.), *The Cambridge handbook of multimedia learning* (pp. 549-568). Cambridge: Cambridge university press.
- Roschelle, J., & Teasley, S. (1995). The construction of shared knowledge in collaborative problem solving. In C. E. O'Malley (Ed.), *Computer supported collaborative learning* (pp. 69-97). Heidelberg: Springer-Verlag.
- Sangin, M., Molinari, G., Dillenbourg, P., Rebetez, C., & Betrancourt, M. (2006). *Collaborative learning with animated pictures: The role of verbalizations*. Paper presented at the International Conference of the Learning Sciences, Bloomington IN.
- Sangin, M., Rebetez, C., Dillenbourg, P., & Betrancourt, M. (submitted). Collaborative learning with animated pictures: From the persistency of information to the split-interaction effect. *Learning and Instruction*.
- Schneider, E., & Boucheix, J.-M. (2006). *Task specificity and user control during the elaboration of a mental model with text and animation*. Paper presented at the Conference of the EARLI Special Interest Group on Text and Picture Comprehension, Aug 30 - sept1, Nottingham.
- Schnotz, W. (2005). An integrated model of text and picture comprehension. In R. E. Mayer (Ed.), *The cambridge handbook of multimedia learning* (pp. 49-69). Cambridge: Cambridge university press.
- Schnotz, W., & Bannert, M. (2003). Construction and interference in learning from multiple representation. *Learning and Instruction, 13*, 141-156.
- Schnotz, W., Böckheler, J., & Grzondziel, H. (1999). Individual and co-operative learning with animated pictures. *European journal of psychology of education, 14*(2), 245-265.
- Schnotz, W., & Rasch, T. (2005). Enabling, facilitating and inhibiting effects of animations in multimedia learning: Why reduction of cognitive load can have negative results on learning. *Educational Technology Research and Development, 53*(3), 47-58.
- Schwan, S., & Riempp, R. (2004). The cognitive benefits of interactive videos: learning to tie nautical knots. *Learning and Instruction, 14*(3), 293-305.
- Schwartz, D. L. (1995). The emergence of abstract dyad representations in dyad problem solving. *The journal of the learning sciences, 4*(3), 321-354.
- Stahl. (2002). *Contributions to a theoretical framework to CSCL*. Paper presented at the CSCL, Boulder, Colorado.
- Sweller, J. (2003). Evolution of human cognitive architecture. In B. H. Ross (Ed.), *The psychology of learning and motivation* (Vol. 43, pp. 215-266). New-York: Academic Press.
- Sweller, J., & Chandler, P. (1994). Why some material is difficult to learn. *Cognition and Instruction, 12*(185-233).
- Sweller, J., Chandler, P., Tierney, J., & Cooper, M. (1990). Cognitive load as a factor in the structuring of technical material. *Journal of Experimental Psychology: General, 119*, 176-192.
- Sweller, J., van Merriënboer, J. J. G., & Paas, F. G. W. C. (1998). Cognitive architecture and instructional design. *Educational Psychology Review, 10*(3), 251-296.
- Thompson, S. V., & Riding, R., J. (1990). The effect of animated diagrams on the understanding of a mathematical demonstration in 11 to 14 years-old pupils. *British Journal of Educational Psychology, 60*, 93-98.
- Van Dijk, T. A., & Kintsch, W. (1983). *Strategies of discourse comprehension*. New York: Academic Press.
- Wechsler, D. (1981). *Wechsler adult intelligence scale - revised (WAIS-R)*. Cleveland: The psychological corporation.
- Wouters, P., Paas, F., & van Merriënboer, J. J. G. (2005). *Observational Learning from animated expert models: The relation between modality, pacing and segmentation*. Paper presented at the Biannual meeting of the European Association for Research on Learning and Instruction, Nicosia, Cyprus.