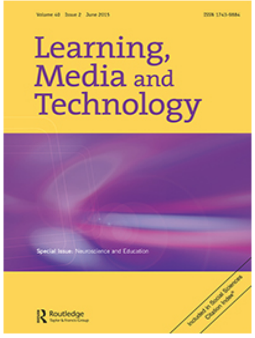

Learning, Media and Technology

ISSN: 1743-9884 (Print) 1743-9892 (Online) Journal homepage: http://www.tandfonline.com/loi/cjem20

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To cite this article: Alessandro Antonietti, Barbara Colombo & Chiara Di Nuzzo (2015) Metacognition in self-regulated multimedia learning: integrating behavioural, psychophysiological and introspective measures, Learning, Media and Technology, 40:2, 187-209, DOI: 10.1080/17439884.2014.933112

To link to this article: http://dx.doi.org/10.1080/17439884.2014.933112

Published online: 17 Jul 2014.

Learning, Media and Technology, 2015
Vol. 40, No. 2, 187–209, http://dx.doi.org/10.1080/17439884.2014.933112

Metacognition in self-regulated multimedia learning: integrating behavioural, psychophysiological and introspective measures

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(*Received 29 October 2013; accepted 5 June 2014*)

This study aims at investigating students' strategies – as revealed by behavioural, psychophysiological and introspective measures – which are applied during the free exploration of multimedia instructional presentations, which requires students to self-regulate their learning processes. Two multimedia presentations were constructed and presented to a sample of 20 undergraduates in two conditions: written text + pictures vs. audio text + pictures. While students were engaged in the study of the presentations, their eye movements were registered and psychophysiological indices were monitored. Students' learning outcomes were assessed and a questionnaire was employed to record students' awareness of the mental processes involved in the task. Results showed that students were able to discriminate between the written- and audio-text conditions and self-regulate their behaviour accordingly. A model, assuming psychophysiological indices as predictors of different eye-movement patterns, highlighted significant differences between the written- and the audio-text conditions. A regression model, considering learning outcomes as a dependent variable, showed that the number of correct responses could be predicted according to the level of cognitive effort needed during the exploration of the multimedia presentations.

Keywords: multimedia learning; self-regulation; metacognition; eye movements; biofeedback

Introduction

In the last decade the use of multimedia tools in educational settings has enhanced the learning environment because the concepts are presented to students in a variety of formats semantically integrated to each other (e.g., oral or written texts with static or dynamic images) (Bagui 1998; Jereb and Šmitek 2006). In this field, the most complete and comprehensive model is Mayer's cognitive theory of multimedia learning (2001, 2005). Starting from several empirical studies, Mayer proposed a general multimedia principle,

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which states that students learn more effectively when they use both words and images during their learning process than when they use words alone. According to this model, a multimedia presentation fosters learning if it is composed by a narrative or a written text integrated with static or dynamic images (Moreno 2005). Mayer (2008) identified several specific principles, derived from this comprehensive one. One that appears particularly relevant in an effective multimedia learning presentation is the modality principle, which we will consider in this paper. This principle suggests presenting words as speech rather than on-screen text since it has been shown that students learn better when new complex information is explained by audio narration than by written words (Clark and Mayer 2011).

Mayer's principles are based on the assumption that words and images are processed by two different cognitive processing channels (verbal and visual) (Paivio 1986). Yet, to ensure learning effectiveness, it is important that there is not an excessive investment of mental effort or overload (Chandler and Sweller 1991) because the two channels can process only a limited amount of information. How much of the effectiveness of multimedia learning relies on the presentation itself and how much relies on the way the student manages the multimedia materials is still open to discussion.

The effectiveness of multimedia learning has been usually tested by asking individuals to examine materials presented in both verbal and visual format, using different kinds of pre-structured presentations, where the variables under investigation were totally controlled by the experimenters. Yet, it may be relevant to investigate what may happen if, as often occurs during everyday learning activities, the student is allowed to access the visual material only if he/she decides to do so. We assume that in this open condition the student has to self-regulate his/her learning process and this may change the learning outcomes even though the multimedia materials are the same.

Self-regulated learning refers to the setting of one's goals in relation to learning and ensuring that the goals set are attained. Self-regulation appears to be effective in learning (Koriat 2012), especially in the presence of new educational materials (Prins, Veenman, and Elshout 2006), in real educational settings (Pieschl et al. 2012) and in hypermedia environments (Azevedo et al. 2010). Specifically, self-regulation appeared to be data-driven when adjusted to intrinsic demands of the task and goal-driven when controlled by the learner (Koriat, Ma'ayan, and Nussinson 2006).

Self-regulated learning is closely related to metacognition, which refers to the processes involved in thinking about thinking (Frith 2012). Learners should possess relevant beliefs (metacognitive knowledge) about the mental operations which are involved in the use of a multimedia presentation, be aware of their own mental operations while studying the multimedia presentation (metacognitive monitoring) and be able to control such operations to direct them towards the goals to be achieved (metacognitive control) (Brown 1987; Zimmerman 1994).

As far as metacognitive knowledge is concerned, the literature suggests that learners develop personal conceptions about the educational technologies that they are asked to employ (Schraw and Moshman 1995) and that such beliefs can influence learning outcomes (Antonietti and Colombo 2008). It has also been proved that students are able to identify the psychological mechanisms that different kinds of computer-supported tools involved (Antonietti, Colombo, and Lozotsev 2008). With specific reference to multimedia tools, it has been reported that not only trainers (Antonietti and Giorgetti 2006; Colombo and Antonietti 2013), but also trainees have adequate beliefs about the mental processes that the combination of texts and pictures activates (Antonietti and Giorgetti 2004; Colombo and Antonietti 2006, 2013; Antonietti et al. 2011).

From a recent review of the literature about the relationships between metacognition and multimedia (Antonietti and Colombo 2014) it emerged that most authors (e.g., Howard-Jones and Martin 2002; Kramarski and Ritkof 2002; Bendixen and Hartley 2003) supported the presence of different aspects and roles of metacognition during multimedia learning. The overall message which emerged was that metacognitive skills can help students to be aware of their cognitive processes, promoting and enhancing, hence, self-regulated learning. According to these studies, the more the learner is able to monitor and control his/her cognitive resources while studying a multimedia presentation, the more the multimedia presentation could be able to meet his/her needs and this may allow him/her to achieve meaningful learning. A recent example can be found in Schwonke et al.'s (2013) study, where metacognitive support reduced the time of overall learning and helped students to fix representations of the subject matter.

It would be interesting, in order to gain a more complete picture of the relationships between metacognition and multimedia learning, to investigate if, when a multimedia tool is provided in an open learning environment, as happens most times in school activity and in homework, are students able to manage their own cognitive resources and decide by themselves, without being instructed to do so, whether and how to deal texts and pictures in order to reach effective learning.

Metacognition explored through an ecological perspective as mentioned previously is important because it guarantees a more relevant application to real-life learning situations. It may allow researchers and teachers to shed light not only on the past cognitive events that led learners to develop their metacognitive knowledge, but also on how their cognitive processes are actually monitored and controlled (Valot 2002). This is especially important since metacognition operates on a combination of different levels. Some levels are linked to short-term mechanisms and cannot be consciously inspected by individuals, who might be sometimes aware of them only briefly in the precise moment of their occurrence and only if instructed to pay attention to them. On the other hand, others levels (more commonly explored) are related to long-term processes, are linked to complex mental representations and are spontaneously tracked by individuals (Valot 2002).

Hence, metacognition can be conceived as articulated at different levels corresponding to the different degrees of awareness people have when facing a cognitive task. This leads to the distinction between implicit and explicit metacognition (Dienes and Perner 2002; Efklides 2008). On the one hand (explicit metacognition), people are fully conscious of what is occurring in their mind, so as to be able to report about them verbally and regulate their learning strategies according to naive theories, which they share and can describe. On the other hand (implicit metacognition), individuals show that their behaviour is strategically controlled in order to reach the proposed goals, but they fail to consciously perceive how their mind is operating, and thus they fail to report it adequately (Clark and Hassert 2013). Thus, it is conjectured that people acquire a genuinely implicit metacognitive knowledge and they apply it to the task they have to carry out. In the framework of self-regulation theories, it has been stressed that the role of the subconscious processes – conceived as a storehouse of knowledge, operations, value judgments, etc. – has to be taken into account since they can guide goal performance implicitly (Locke and Latham 2006). It is assumed that at the subconscious level an enormous amount of content and processes are stored, which can influence behaviour without awareness (Stajkovic, Locke, and Blair 2006). As a consequence, it is possible for implicit measures to show greater change than explicit measures in order to highlight the strategies underlying self-regulation (Petty, Wheeler, and Tormala 2003; Petty and Briñol 2009).

Metacognition is a relevant topic also because, since the role of the prefrontal cortex in regulating metacognitive aspects has been suggested (Fleming and Dolan 2012), making a link shared between education and neuroscience. An interesting model that explicitly links metacognition to neuroscience is the one proposed by Frith (2012). The author, focusing on the neural basis of metacognition, stresses that many metacognitive functions are associated with executive control instangated in prefrontal cortex. He also highlighted that this link is methodologically relevant; using advanced signal detection techniques and transcranial stimulation allows the investigator to get a more precise measurement of metacognition, confirming at the same time that frontal cortex has a causal role in supporting metacognition.

In this study, starting from the theoretical assumptions outlined above, we followed Frith's (2012) hint at linking metacognition, education and neuroscience and used sophisticated methods – i.e., eye tracking and psychophysiological indicators – to reveal the points in multimedia processing in which major decisions are being made regarding the need to ask for pictures in order to understand information presented either as written text or in an audio format.

The recording of eye movements during a multimedia presentation can be a way to assess the possible presence of a strategic approach (Underwood and

Radach 1998; Chuang and Liu 2012). In fact, eye movements can be considered as informative about individuals' cognitive elaboration of the target stimuli. Eye fixations, which concern the maintaining of the visual gaze on a single location, suggest that information has been processed by the cognitive system, according to the 'mind-eye hypothesis' (Just and Carpenter 1980; Rozenblit, Spivey, and Wojslawowicz 2002). In agreement with Jacob and Karn (2003), the number of fixations can be related to the observer's search for relevant information. The frequency of fixations reflects the importance of a specific element within the stimulus, whereas the duration of fixations can lead investigators to identify the areas of interest (AOI) to the observer. However, a very long fixation may also mean that the observer perceives it difficult to process information (Chuang and Liu 2012).

Benefits of using eye tracking to assess cognitive and metacognitive processes, as well as cognitive load, in computer-based learning environments have been discussed by Van Gog and Jarodzka (2013). The authors listed several strengths, such as the very detailed information on the observer' gaze, the order according to which the elements of the stimulus are explored and for how long a visual stimulus, or a part of it, is actually explored.

Thanks to eye tracking, Eitel, Scheiter, and Schüler (2013) were enabled to derive the notion that when students explore pictures before processing written or spoken text, global information extracted is used as a scaffold to facilitate the construction of a mental model, as shown previously (Schnotz and Bannert 2003; McCrudden, Magliano, and Schraw 2011). In another eye-tracking study, abstract figures, compared to concrete representations, enabled more efficient processing of the text, even though a greater effort to integrate verbal and pictorial information is needed to do so (Mason et al. 2013). Hence the measurement of eye movements, a non-intrusive but informative methodology, may provide researchers relevant real-time data about the learners' cognitive processes.

Since we were interested in exploring the cognitive effort, together with participants' attentional focus, we decided to combine eye tracking with a tool allowing us to monitor students' physiological activation while they were looking at the multimedia presentation. Physiological indices, recorded using biofeedback (BFB) equipment, have been used to assess the participants' degree of cognitive effort during a multimedia presentation.

Psychophysiological indices are another useful candidate to reveal learners' implicit strategies during a task. In fact, these measures can mirror a person's underlying cognitive activity (Andreassi 2006; Kim et al. 2013; Sutarto, Wahab, and Zin 2013). Both Meyer and Kieras (1997) and Manzey (1998) argued that cardiovascular indices and indices related to respiration could be indicative of cognitive workload. This is true because these indices can be interpreted as a direct marker of arousal and hence an indirect measure of mental workload. Mulder et al. (2000) confirmed that the role of cognitive load can be investigated by studying markers, such as, those related to arousal. Tsianos et al. (2010) reported that heart rate, but not skin conductance and pulse volume, was significantly correlated with self-reported anxiety. Moreover, electrodermal activity increases in the pre-decisional phase of a cognitive process, highlighting that the individual is preparing him/herself to face the task by increasing the amount of resources he/she will need (Palomäki et al. 2013).

This study aims to investigate students' metacognitive monitoring and control when they are free to explore a multimedia presentation presenting new materials to be learned. We intended to analyse to what extent learners are aware of how they process (or may process) the materials being presented to them.

More specifically, the present study addresses:

- The validity of the modality principle in an open learning environment. We hypothesised that students will achieve a better learning performance when materials are presented through the combination of audio tracks and pictures than when they are presented through texts and pictures.
- The possible presence of self-regulated learning strategies applied to a multimedia presentation as revealed by the choices to access pictures, eye movements and psychophysiological reactions (implicit metacognition). We expected to identify behavioural correlates of the attention regulation according to the content and the kind of multimedia presentation as mirrored by the number and the length of on-screen fixations. We also expected to record higher activation (as revealed by psychophysiological reactions) when students have to integrate text and pictures.
- The possible presence of metacognitive awareness underlying the strategies (explicit metacognition). We hypothesised that students will be able to refer in a coherent way about the self-regulation strategies they applied.
- The hypothesised direct positive relationships between implicit and explicit metacognition and between these dimensions and the learning outcomes.

Methods

Instruments

Multimedia presentations

Starting from the multimedia presentations used in the experiments by Mayer (2001), two new presentations on two different topics – comparable to those made by Mayer for length, structure and complexity of the text – were devised. The contents had been chosen to mirror the structure of Mayer's presentations, avoiding gender bias and motivational differences and assuring that participants had no previous knowledge about the topics the presentations were focused on.

One presentation explains how an invisibility cloak, built by engineers in a university laboratory, works; the other presentation explains how to change frets on a renaissance lute. Both presentations were segmented into 16 short steps, each associated with an illustration. For each of these steps, two versions were created: one with the text presented in a written format and another with the text presented orally, for a total of four experimental conditions: two topics (invisible cloak and lute) × two modalities (text and audio).

Each presentation had the following structure:

- A short passage for each conceptual step of the explanation appeared in the upper left part of the screen in the text condition. In the audio condition, a small icon appeared in the same position in order to be an analogous focus of visual attention for participants; in this case, the audio registration of the passage was presented to the participants through earphones.
- During both the text and audio presentations, participants could ask for the illustration corresponding to the passage they were currently exposed to by just saying aloud the word ‘picture’.

Examples of passages from the two presentations can be seen in Figure 1.

After 100 milliseconds from the request, the illustration appeared in the upper right portion of the screen and remained there until the following presentation step. We used this manner to allow participants to access the pictures, but not requiring them to press a button (as usually done), since they could not

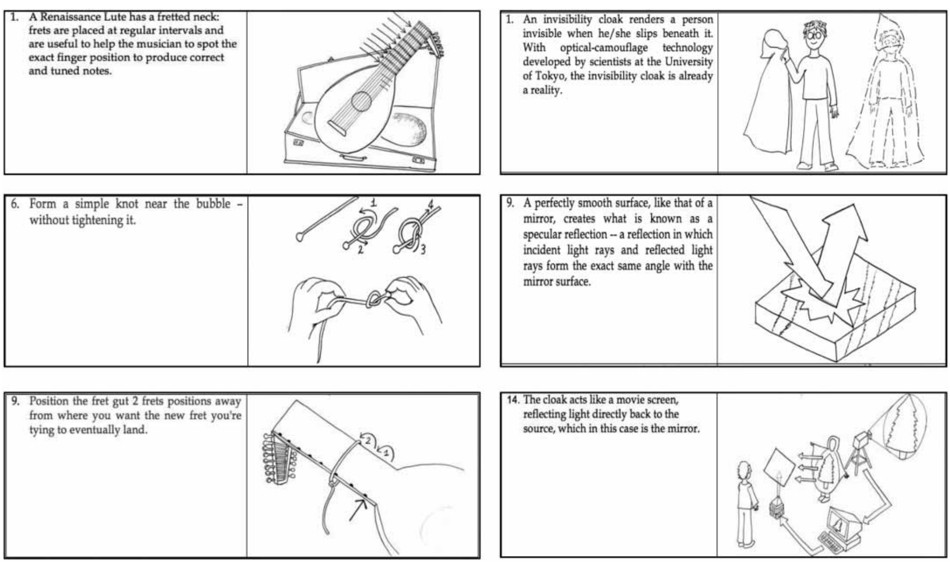

Figure 1. Examples of passages from the two presentations with the corresponding pictures.

move their hands as this would interfere with recording the psychophysiological data. Timing of requests was automatically recorded by the software that was used to show the multimedia presentations.

After a given time, corresponding to the time needed to read the text passage slowly (as occurred in the audio condition), the current passage (and the associated picture, if displayed) was removed and the next passage appeared.

Illustrations included in the multimedia presentations were classified in a dichotomous way: as 'critical' (if they were associated with a complex passage of the presentation which was hard to be understood) or 'not critical'. Pictures were labelled as critical on the basis of scores recorded previously from a pilot sample of undergraduates, who were asked to rate each passage of the presentation by assigning a score from 1 (very easy) to 5 (very difficult). The median of the distribution of the scores was used as the cut-off point between critical and not-critical pictures.

Eye tracking

During the presentations, visual-behavioural indices were registered by means of an eye tracker (ET), an instrument that uses video-oculography to record the eyes' position and movements within the orbit. Visual exploration, fixation length, fixation duration and time to the first fixation can be recorded through ET.

In this study *Tobii x-120* ET equipment was used. This system allows experimenters to perform a rapid and automatic calibration procedure for each participant and is characterised by a tolerance for large head movements. This feature permits participants to move freely and naturally. This system is completely unobtrusive, ensuring the natural behaviour of subjects and valid research data.

To record ET indices, we created three AOI, corresponding to the position of the text (or to the screen background, in the audio condition) (AOI1), the position of the picture (AOI2) and to the empty space under these two areas (AOI3). Data were analysed by means of the *Tobii Studio* software, which allows investigators to collect quantitative data concerning the number and length of fixation for each AOI, the time before the first fixation and the length of the first fixation.

Psychophysiological measures recording

The *Biofeedback 2000$^{x\text{-}pert}$* (*Schufried GmbH*, Austria) equipment was used to record psychophysiological reactions. BFB is a non-invasive instrument, which monitors and records an individual's physiological activity. Thanks to a sensor connected to the participant's finger, physiological indices – skin conductance (SCL), skin temperature (TEMP) and pulse volume amplitude (PVA) – are recorded and directly delivered to the *2000$^{x\text{-}pert}$* software via Bluetooth and visually displayed on a computer monitor supervised by the experimenter during the entire session. Participants do not have any access to this information any time during the experiment. The sensor does not cause any pain or discomfort to the participant.

Metacognitive questionnaire

After looking at the multimedia presentations, participants completed a questionnaire. They were asked to answer questions about each passage of each presentation; this allowed us to understand exactly which aspect of the presentation participants' were referring to.

Questions concerned the perceived difficulty of the passage, the perceived utility of the corresponding picture (if displayed), the reason why they requested that picture, if they would change the decision to request that picture and the timing (i.e., if they would have requested the pictures sooner or waited longer in order to process the audio text before asking). Participants were asked to express their responses on a five-point scale (except for the question about why they requested the illustration; in this case a list of reasons was listed and they had to endorse one of them).

Assessment of the learning outcomes

By applying the same procedure employed by Mayer (2001), we evaluated learning outcomes related to memory (retention) and problem solving (troubleshooting and redesign).

The retention task consisted in asking participants to list the passage of the presentations as they remembered them, without trying to follow the exact presentation order. Troubleshooting questions presented individuals with a problem that had to be solved. Suggestions for solving the problem were given during the presentation, but inferences had to be made by the participants in order to answer the questions. An example of troubleshooting questions for the lute presentation is: 'You changed your frets but the lute is making a strange sound and one string is not vibrating. What could you do to solve the problem?'. Redesign questions asked participants to change a feature related to the target topic in order to fit a specific requirement. Once again, participants needed to make inferences starting from the clues provided in the multimedia presentation in order to be able to answer the questions. An example of a redesign question for the cloak presentation is: 'Imagine being asked to change the invisibility cloak in order to make it appear that people look like they are wearing different clothes instead of making them appear invisible. What would you change?'

The criteria for scoring responses to the retention, troubleshooting and redesign questions are reported in Table 1.

All evaluations were made by two independent trained judges, who showed a high level of agreement ($k = .82$, $p < .001$). All ambiguous cases were discussed in order to reach a unanimous score.

Table 1. Criteria for scoring the retention, troubleshooting and redesign responses.

Type of question	Scale used to evaluate answers	Scale grades	Computed index
Retention	10-point scale	1 = completely inadequate learning 10 = perfectly adequate learning	Memory Index (based on the mean scores)
Troubleshooting	10-point scale	1 = completely inadequate answer 10 = perfectly adequate answer	Troubleshooting Index (based on the mean scores)[a]
Redesign	10-point scale	1 = completely inadequate answer 10 = perfectly adequate answer	Redesign Index (based on the mean scores)[a]

[a]These two indices have been considered together (computing a general mean) as problem-solving index in some analyses.

Participants

The sample was composed of 20 undergraduate university students (16 females and 4 males). Their age ranged from 23 to 25 years (mean = 23.4 years, SD = 1.78). Students enrolled in the faculties of psychology and of education were not included in the sample in order to exclude the possible influence of ideas concerning multimedia learning acquired during courses where they might have discussed this or a related topic.

Procedure

Each participant watched two presentations (one in the text and the other in the audio condition) in a balanced design in the sample according to content, format and order of presentation (so that the lute presentation in the audio format, the lute presentation in the text format, the cloak presentation in the text format and the cloak presentation in the audio format were presented the same number of times and each of them was presented the same number of times as the first and as the second presentation). Participants had the opportunity to ask to see when needed and for a maximum of eight times (half of the number of the available illustrations), the picture corresponding to the passage he/she was reading or hearing about. We decided to set a limit to the number of images that participants could request because otherwise, instead of strategically regulating their learning process by asking only for the illustrations they need to foster a better comprehension, they would just request all the available pictures, as has been noticed in a pre-test we run on the presentations.

Behavioural and psychophysiological indices were simultaneously recorded while participants were studying the presentations.

As noted previously, after the session participants had to respond in writing to a questionnaire to assess their metacognitive awareness during the exploration of the multimedia presentations.

Finally, questions about the content of the multimedia presentations were asked; participants answered them in writing.

Results

Analyses were carried out starting from the general evaluation of the validity of the modality principle in our specific context, examining then the role of participants' implicit self-regulation strategies during the exploration of the multimedia presentations and focusing as the last step on metacognitive awareness.

Validity of the modality principle in an open learning environment

Independent-sample *t*-tests showed that learning outcomes were better in the audio than in the text condition, as showed both in the retention ($t = 1.95$, $p < .05$; Figure 2) and in the problem-solving questions ($t = 1.82$, $p < .05$; Figure 2).

Implicit strategies as revealed by behavioural indices

By applying an independent-sample *t*-test, we considered the number of requested pictures to assess in which experimental condition the support of illustrations was most needed. The total number of required pictures was higher in the audio than in the text condition ($t = 2.01$, $p < .05$; Figure 2).

That is, the request for critical illustrations was higher in the audio than in the text condition. Specifically, 53% of participants in the audio condition, vs. 38% in the text condition, required pictures classified as critical. The difference between the two percentages was statistically significant ($z = 1.88$, $p < .05$).

The number of requested pictures was positively correlated to the troubleshooting index of learning outcomes (Table 2).

Eye-tracking measures showed that the numbers of fixations and the fixation lengths were higher (respectively, $t = 2.60$ and $t = 2.72$) in the audio than in the text condition with regard to the AOI = picture (Table 3). The same was true by weighting the mean values by considering the number of pictures requested by each participant (numbers in brackets; the statistical significance of the tests remained unchanged).

Observing the pictures often and for a long time was positively correlated to good answers in the troubleshooting questions in the text condition.

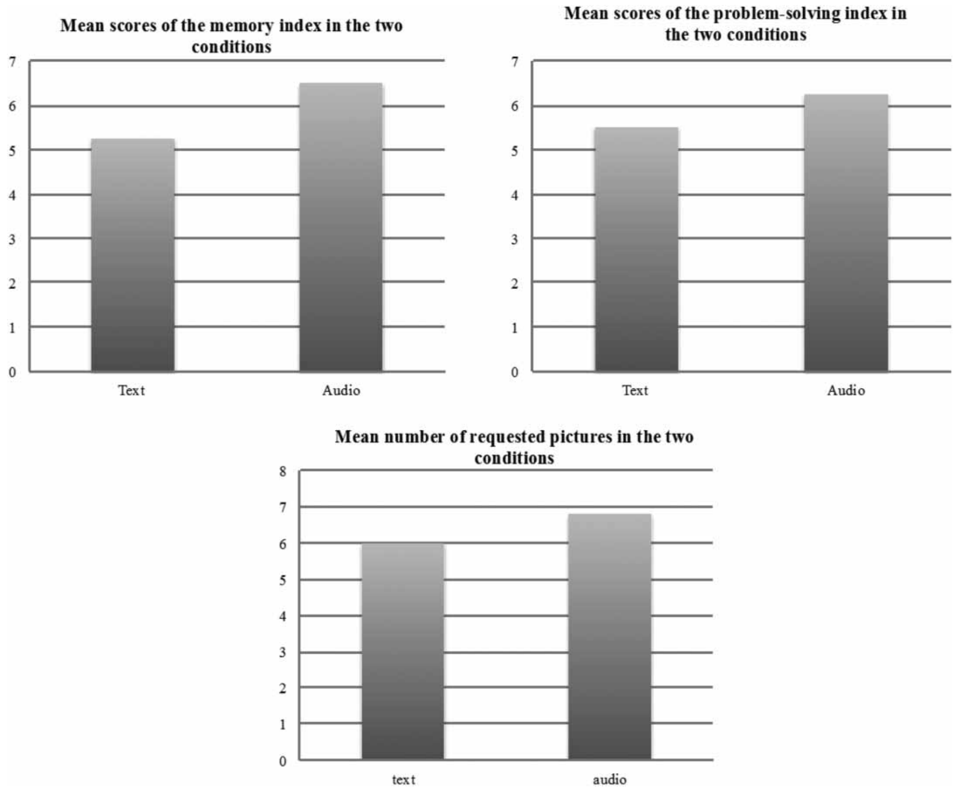

Figure 2. Mean scores of memory index, problem-solving index and number of requested pictures.

Instead, the observation of figures showed negative correlations with recall questions in the text condition and with redesign questions in the audio condition (Table 4); this means that observing images for a longer time did not promote a better memory of the content per se (i.e., poorer results in the retention tests) but fostered a better understanding of the topic (i.e., better results in redesign questions).

Table 2. Correlations between the number of requests for pictures and learning outcomes.

	Learning outcomes			
	Condition	Retention	Troubleshooting	Redesign
Total number of requested pictures	Text	−.12	.49*	−.11
	Audio	−.34	.61**	−.27

*$p < .05$.
**$p < .01$.

Table 3. Mean values (SDs in parentheses) of the eye-tracking indices concerning the requested pictures in the two conditions.

ET Indices	Condition	
	Text	Audio
Fixation number	37 (4.23) [6.17 (1.44)]	75 (5.12)** [11.03 (2.01)]**
Fixation length	16 (3.16) [2.67 (0.65)]	29 (3.98)** [4.26 (0.92)]**
Time before the first fixation	26 (4.44)	18 (4.00)
First fixation length	0.18 (0.07)	0.26 (0.09)

**$p < .01$.

Psychophysiological indices

A general linear model (GLM) model was computed assuming the eye-tracking measures as dependent variables and the psychophysiological activation as moderating variable. Psychophysiological indices were not intended as a dependent variable, since the presentations were not cognitively so demanding – or the setting so stressful – to make us expect huge variations of these indices. Yet, we assumed that they could have a moderating effect on the target cognitive variables; this means that we expected the level of individual cognitive activation, as expressed by the psychophysiological indices, to influence the strength of the relationship between the type of presentation (audio vs. text condition for the different presentation contents) and participants' attentional behaviour (as recorded using ET measures) while studying the presentations.

As can be derived from the data reported in Table 5, in the audio condition differences between the three AOIs emerged (i.e., participants were not focussing on a specific point of the screen) and all differences occurred at the very beginning of the exploration of the multimedia presentation. In addition,

Table 4. Correlations between eye-tracking data (AOI = picture) and learning outcomes.

Learning outcomes	Text		Audio	
	Fixation length	Fixation number	Fixation length	Fixation number
Recall	−.78***	−.11	.02	−.31
Troubleshooting	.62**	.47*	−.13	−.37
Redesign	.14	.02	−.15	−.62**

*$p < .05$.
**$p < .01$.
***$p < .001$.

differences between the two contents linked to the orientation of attention emerged. More specifically, in the audio condition the lute presentation elicited a longer pause before the first fixation to the main areas of the screen (i.e., subjects waited before focusing their attention to the screen areas where information was displayed, probably paying attention and focusing on the audio information) and a longer first fixation to the lower part of the screen (coherently with what stated above, they would focus on a non-informative part of the screen in order to better focus on the audio information). By analysing individuals' visual behaviours in the video condition differences between the two presentations related to the number of fixations emerged as well; participants showed a higher number of fixations in the picture area in the cloak presentation.

Results also highlighted a significant moderating role of psychophysiological measures. We computed the beta weights (*B* values) and their significance in order to understand the main directions of this influence. Results are reported in Table 6. In the audio condition, the moderating variables showed a positive relation with the visual behaviour; participants who delayed the first fixation and/or lengthened the first fixation in the neutral area of the screen were more aroused. This mirrors a general activation (higher temperature values) for the neutral part of the screen and for the left part of the computer screen (empty in the audio condition), which was useful to allow participants to focus attention onto the audio message. Students were also more tense before looking at pictures and devoted more time to get ready for image processing, as reflected by a positive relationship between PVA levels and Time-to-First-Fixation on AOI = picture. In the text condition, considering the areas where

Table 5. GLM with mean differences between contents in different conditions related to participants' visual behaviour.

Area of interest	ET measure	Content	Mean	SD	$F_{(11,8)}$	p	Partial η^2	R^2_{adj}
Audio condition								
AOI1 (upper left)	Time to first fixation	Lute Cloak	18.27 4.58	20.92 5.06	3.78	$<.05$	.84	.62
AOI2 (upper right – picture)	Time to first fixation	Lute Cloak	10.45 3.21	21.87 2.87	8.30	$<.01$	.92	.81
AOI3 (bottom – blank)	First fixation duration	Lute Cloak	.90 .17	1.44 .10	5.20	$<.01$	.88	.71
Text condition								
AOI2 (upper right – picture)	Fixation count	Lute Cloak	14.16 19.72	14.87 13.28	3.24	$<.05$	.82	.56

Table 6. Influence of moderating variables (psychophysiological indices) in the GLM model.

Area of interest	ET measure	Index	*B*	*p*
Audio condition				
AOI1 (upper left)	Time to first fixation	TEMP	13.20	<.01
AOI2 (upper right – picture)	Time to first fixation	PVA	7.91	<.05
AOI3 (bottom – blank)	First fixation duration	TEMP	0.81	<.01
Text condition				
AOI2 (upper right – picture)	Fixation count	SCL	−720.63	<.01
		TEMP	268.99	<.01
		PVA	−162.20	<.05
		PULS	223.52	<.01

illustrations were displayed, we got a more complicated picture. Undergraduates were the more relaxed (as mirrored by the negative relationship between both SCL and PVA values) the more they looked at pictures (in the cloak presentation), but also the more cognitively activated (as mirrored by the positive relationship between both PULS and TEMP values). Hence looking more at the pictures in the text condition appeared to help students focusing on what they were learning, presumably in order to gain more confidence.

A linear regression model was applied to assess the influence of the psychophysiological indices on learning outcomes. The model was significant (as reported in Table 7) when considering the problem-solving scores, for both audio and text conditions. In the audio condition, a higher level of SCL was associated with better retention scores. The opposite was true for the text condition. PVA was positively related to performance in the problem-solving questions related to the text condition, probably mirroring a more general emotional activation during the whole multimedia presentations, which led to a better performance.

Table 7. Linear regression testing the influence of psychophysiological indices on learning outcomes (transfer).

	b	SE*b*	*β*
Transfer			
Constant	1.50	.12	
SCL audio	1.56	.75	2.82**
SCL text	−1.83	.70	−2.34*
PVA text	0.49	.20	0.62*

Note: $R^2 = .77$; $p < .05$.
*$p < .05$.
**$p < .01$.

Metacognitive awareness

Participants perceived a higher degree of difficulty in the final parts of each presentation, which, for both contents, presented the most complex conceptual issues. Participants were also able to recognise the points of each presentation that were more difficult to understand (for example, the 11th step for the lute and the 12th for the cloak), by requesting the pictures accordingly (see Figure 3).

Data from the metacognitive questionnaire showed that individuals considered the illustrations in the audio condition most effective and reported to have used them in order to integrate the specific aspects of the explanation (50%) and, in retrospect, they would have changed the request timing of images (i.e., they would have requested the images sooner, or waited longer or both) (50%). In the text condition, on the other hand, participants would have changed the number of required images (44.4%) and the timing request (44.4%).

Finally, correlations between efficacy scores attributed to images and eye-tracking data and learning outcomes confirmed the perceived effectiveness of the visual support in the audio condition (Table 8).

Discussion and conclusions

The results of the present study showed that in a multimedia presentation the audio condition, where images are associated with a narrated animation, resulted in better learning performance than the text condition where the

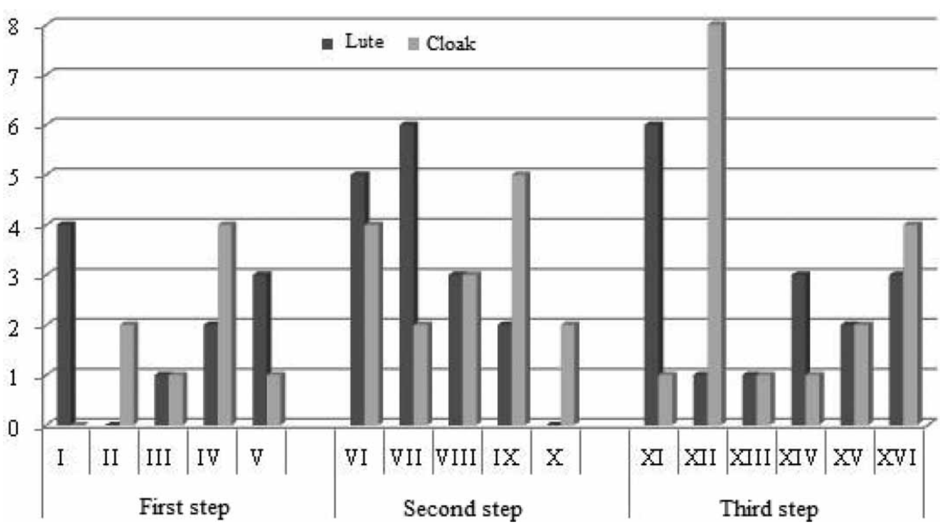

Figure 3. Comparisons between pictures requested in the two conditions, in the first, second and third part of the presentations.

Table 8. Correlations between utility scores in the two conditions and learning outcomes and eye-tracking data.

	Condition	
	Text	Audio
Learning outcomes		
Recall	−.07	−.29
Troubleshooting	−.27	−.14
Redesign	.31	−.28
ET data		
Fixation length	−.01	.53*
Fixation number	.01	.74***

*$p < .05$.
***$p < .001$.

same ideas were presented as on-screen text. Hence, these data are perfectly in line with Mayer's modality principle, confirming that the presentation of information in the same format hinders their cognitive processing and that illustrations, if combined with audio texts, enhance learning once they are accessed when the concepts are difficult to comprehend. Thus, we can maintain that the modality principle is valid not only in multimedia presentations based on the assumption that learners should pay attention both to verbal and pictorial information, but also when they are free to choose when illustrations merit to be taken into account.

When enabled to regulate their own exploration of the multimedia presentation, in the audio condition participants requested more images, showing a behaviour that mirrors what would be predicted by Mayer's theory.

In the audio condition, moreover – given the greater number of required images, especially images linked to critical and complex points of two presentations and given the increased number fixations on the requested images, as well as the longer duration of fixations – we realised that participants exerted an adequate implicit control on their learning process. Even though a direct relation between eye movements during the multimedia presentation and learning outcome failed to emerge in all conditions and on all learning measures, it is apparent that students differentiated their ocular behaviour according to the content and format of the presentation they were faced with.

Also psychophysiological states differed during the different stages and conditions of multimedia learning. We know that electro-dermal activity increases in the pre-decision-making process (Palomäki et al. 2013) and it is hence possible to argue that in the audio condition participants spent more energy trying to make the right decision whether to ask for an image and were more activated in order to prepare for the subsequent processing of the requested illustrations. These anticipatory processes resulted in better learning outcomes.

When information was displayed on the screen, less effort was required to keep and retrieve data in working memory, a process that has been shown to influence SCL values (Fioravanti et al. 2004). It is worth mentioning that PVA levels are associated with cognitive effort (Lai, Li, and Lee 2012).

The metacognitive questionnaire highlighted that participants attributed great value to the images which they requested and endorsed the most elaborated reason (i.e., pictures facilitate cognitive integration) to justify their judgments. This is indicative of relevant explicit metacognitive knowledge. The questionnaire showed that participants were able to discriminate among the different steps of the presentations, assigning higher efficacy scores to the pictures associated with complicated passages. For example, the first image of the lute presentation obtained higher efficacy scores, since many participants had never seen a renaissance lute before. On the other hand, the cloak presentation was very easy at the beginning, presenting very basic concepts, whereas the last step, presenting the whole mechanism, was rather complicated and so the higher utility scores assigned to images linked to the last phase of the cloak presentation, confirmed that participants had perceived this aspect.

In conclusion, the present study supported the notion that undergraduates are able to manage strategically their behaviour when they are engaged in learning from a multimedia presentation by deciding by themselves what pictures should be assessed to help them understand the difficult concepts involved in verbal descriptions. Such self-regulatory skills emerge both in the choice of the illustrations to be displayed and in the focusing of attention as revealed by eye movements, with psychophysiological reactions mirroring the fluctuation of effort and involvement that cognitive strategies imply. This finding stresses the need to take advantage of students' metacognitive awareness during multimedia learning in order to enable students to benefit the most from the multimedia experience.

Results from this research, whose strongest point may be in integrating different methodologies to assess explicit and implicit metacognitive behaviours, can lead to interesting implications, both at a theoretical-methodological level and at a practical one.

Considering the first level, our data highlight a positive outcome as a result of applying an integrated methodological approach to assess implicit and explicit metacognition. Specifically, the use of technologies such as eye tracking and BFB used to record covert processes (which are mirrored by eye-movements and psychophysiological reactions) as an addition to traditional cognitive measures, proved to be effective. It was actually possible to highlight their active role in mediating the relationship among other variables. Apart from the theoretical relevance of this data, which can enrich the traditional models of multimedia learning, they also suggest some practical implications. Our results point towards implementing more advanced and interactive multimedia presentations that, giving more space to students' metacognitive skills, do not prompt a lot of information (that may not be useful to foster learning) but can be modelled around student's requests. A more advanced step could include the analysis of individuals' implicit responses (e.g., eye movements) to learning materials to build a personalised learning path. Such measures could be integrated in existing systems, such as the Meta-tutor, devised by Azevedo and Strein (2011); this is a learning environment, designed to track scaffold and respond to students' emotions during learning. Having some precise indication about which implicit measures can be useful to develop this advanced learning systems is relevant, because the literature reports that intelligent tutoring systems are not always effective in promoting learning. A recent review by VanLehn (2011) showed that the effect size of intelligent tutoring systems tends to be quite high, so they are nearly as effective as human tutoring. Yet, the authors also highlight how more information about the specific support/ interaction type that these systems should give is still under debate. Our data can be useful in answering this question.

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