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Abstract

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Does animation enhance learning? A meta-analysis

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A B S T R A C T

This meta-analysis investigated whether animation is beneficial overall for learning compared to static graphics, while also identifying moderator factors affecting the global effect. A systematic search was conducted for experimental studies comparing the impact of animated vs. static graphics displays in the context of knowledge acquisition. A total of 50 papers were considered, and consecutively 61 primary studies ($N = 7036$), yielding 140 pair-wise comparisons of animated vs. static graphic visualizations in multimedia instructional material were analyzed using a random-effects model. An overall positive effect of animation over static graphics was found, with a Hedges's g effect size of 0.226 (95% confidence interval = 0.12–0.33). Additional moderator analyses indicated substantial effect sizes when the animation was system-paced ($g = 0.309$), when it was coupled with auditory commentary ($g = 0.336$) or when the instruction did not include any accompanying text ($g = 0.883$).

1. Introduction

In the last two decades, increased computer capacities and expansive use of computers in learning situations have resulted in the tremendous development of multimedia instructions in initial or continuing education. One particular instance of multimedia instruction is animation, in which objects appear to move continuously. Animation is a term frequently used in literature, with a degree of uncertainty around its delineation. This paper will use the definition first suggested by Bétrancourt and Tversky (2000) who saw it as “any application, which generates a series of frames, so that each frame appears as an alteration of the previous one, and where the sequence of frames is determined, either by the designer or the user” (p. 313). As it conveys change over time, animation should be particularly beneficial for memorizing and understanding dynamic systems such as biological processes, natural phenomena or mechanical devices.

Though a vast number of studies have been conducted in the last decade to investigate the effect of animation on learning, there is little empirical evidence to support the hypothesis of the instructional benefit of animation. Literature reviews on studies comparing animated and static visualizations report inconsistent or inconclusive findings regarding the effect of animation on learning (Bétrancourt & Tversky, 2000; Hegarty, Kriz, & Cate, 2003; Moreno & Mayer, 2007; Schneider, 2007; Tversky, Bauer-Morrison, & Bétrancourt, 2002). In many studies, the animation condition did not significantly lead to better learning outcomes than the static condition. The explanations provided to account for the lack of difference were often highly speculative and rarely based on objective data. In other studies, the two conditions differ from each other relative to factors

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other than the visualization per se, such as an unequal amount of information conveyed by both displays, or non-equivalent procedures used in the conditions (Bétrancourt & Tversky, 2000).

Höffler and Leutner (2007) reviewed a large body of research on the instructional effectiveness of animation compared to static graphic displays, by conducting a meta-analysis of 76 pair-wise comparisons out of 26 studies, covering the period 1973–2003. The meta-analysis procedure allows the synthesizing of a large number of pair-wise comparisons. Its advantage over a qualitative review is that it standardizes findings across studies for direct comparison (Lipsey & Wilson, 2001). Results led to an overall beneficial effect of animation over static graphics, with a medium overall effect size of $d = 0.37$, and the identification of several moderating factors.

After a first phase in the 1990's where research focused on the comparison between dynamic versus static graphics in terms of learning outcomes, it became necessary to understand the mechanisms that would *explain* a differential learning effect (Hegarty, 2004b). This last decade has seen a shift in multimedia research towards assessing the conditions under which and the reasons why dynamic representation displays may improve or facilitate learning. Research now investigates the cognitive processes involved in processing dynamic visualization and the steps that lead to the comprehension of the content at hand, and ultimately to learning. Usually in multimedia research, learning refers to the construction of a mental model of the spatial, temporal and functional components of the dynamic content (Lowe & Boucheix, 2008; Narayanan & Hegarty, 2002; Schnotz, 2005). While the conditions of its instructional effectiveness are still unclear, the factors that influence the processing of animation have been largely identified. Three categories may be distinguished; those a) *specific to the learners*, such as their prior knowledge level (ChanLin, 1998; Kalyuga, 2008) and visuospatial ability (Hegarty & Sims, 1994; Lowe & Boucheix, 2009; Yang, Andre, & Greenbowe, 2003), b) *specific to the instructional material*, such as the type of dynamic changes within the animation (Lowe, 2003), its perceptual salience (Lowe & Boucheix, 2009; Schnotz & Lowe, 2003), the presence of accompanying information (Ginns, 2005; Moreno & Mayer, 1999; Tabbers, 2001) or the control over the pace of the animation (Fischer, Lowe, & Schwan, 2007; Mayer & Chandler, 2001), and *c) specific to the learning context* – e.g., the type of knowledge and the instructional domain (Bétrancourt & Tversky, 2000; Schneider, 2007).

By including recent studies and new moderator variables, this present meta-analysis will complement the first meta-analysis conducted on this topic by Höffler and Leutner (2007).

1.1. Instructional functions and cognitive processing of animation

Animations in instruction may be used for several purposes. Firstly, they can be used as an attention-gaining device, attracting learners' attention to a specific area of the instructional material. Animated cues or arrows fall in this category. Secondly, animation may be used as a demonstration of concrete or abstract procedures to be memorized and performed by the learner, such as tying nautical knots (Schwan & Riempp, 2004) or completing puzzle rings (Ayres, Marcus, Chan, & Qian, 2009). A third purpose of animation is to help learners understand the functioning of dynamic systems that change over time, with an analogous and continuous representation of the succession of steps, such as in the flushing system (Hegarty et al., 2003; Narayanan & Hegarty, 2002), or in lightening formation (Mayer & Chandler, 2001). The animations taken into account in this meta-analysis fall into this latter category. There are two reasons behind this choice. One is that these expository animations have been more frequently studied in the multimedia literature than other types of animation. The other is in their ability to support conceptual understanding.

Expository animations can serve three instructional functions (Hegarty & Just, 1993; Narayanan & Hegarty, 1998). First of all, they can convey the configuration of a system or a structure. In this case, animations depict how the parts or elements of a system are integrated or decomposed and give learners the "raw material for building hierarchically organized mental representation" (McNamara, Hardy & Hirtle, 1989; cited by Schnotz & Lowe, 2008, p. 313). Secondly, animations can convey the system dynamics, by explicitly representing the behavior or movement of its components (Schnotz & Lowe, 2003). Thirdly, animation can convey the causal chain underlying the functioning of dynamic systems. The understanding of the causal chain is favored by showing the temporal order of the events occurring within the system (Narayanan & Hegarty, 2002).

There are advantages as well as disadvantages to animation in comparison to static visualization. As concerns the positives of animation, an obvious advantage is its ability to directly depict the spatial organization of the elements (Bétrancourt, Bauer-Morrison, & Tversky, 2001). As changing information has to be inferred by learners from a series of static graphics, animation provides the direct visualization of the microsteps that are the *minute changes* occurring in a dynamic system, thus avoiding misinterpretation and cognitive overload (Bétrancourt et al., 2001; Tversky et al., 2002). Conversely, a series of simultaneously presented static graphics allows for the different states or steps within a depicted process to be consulted and compared, while they are never presented at the same time in an animation (Bétrancourt et al., 2001).

Current views on learning from multimedia information assume that after being selected and organized, information from different sources is integrated within a mental representation linking the new information with previous knowledge (Mayer, 2005; Schnotz, 2005). These processes occur in working memory and are demanding in terms of cognitive resources. Providing animation can lower cognitive demands since dynamic changes are directly perceived and do not have to be inferred. However, it is important as Tversky et al. (2002) recommend, that animations only depict changes that match the learning objectives and do not provide extra information. This helps learners build the conceptual model for which the animation was designed.

From a cognitive point of view, Schnotz and colleagues (Schnotz & Rasch, 2005; Schnotz, 2005) described the potential benefits of animation to learning in terms of enabling and facilitating effects. The continuous depiction of changes in animation supports the perceptual and conceptual processing of dynamic information, which would be impossible to achieve for novice learners in the domain (*enabling effect*) or very demanding from a cognitive resource point of view (*facilitating effect*). The enabling effect is akin to the supplantation effect (Salomon, 1994), which refers to an external cognitive aid for mental operations or processes. A drawback of the facilitating effect is that it may lead learners to an “illusion of understanding” (Schnotz & Lowe, 2003; Schnotz & Rasch, 2005) as well as shallow processing of the conceptual relations underlying the changes. This drawback has also been identified under the term “underwhelming effect” (Lowe, 2003) that is when learners do not allocate enough cognitive resources to understand the animation.

Regarding the disadvantages, animation can be challenging for learners, especially because of the amount of information to be processed (Bétrancourt & Realini, 2005) or its transient nature (Ainsworth & VanLabeke, 2004; Bétrancourt et al., 2001; Lowe, 1999). The transience of the animation, which by definition has to be processed in motion, could lead to difficulty perceiving all the simultaneous basic changes (Bétrancourt et al., 2001). Moreover, the abundant and transient information extracted from animation must be processed and retained by working memory before subsequent processing. This in turn can lead to cognitive overload, inaccessible information and task failure (Jones & Scaife, 2000; Lowe, 1999; Mayer & Moreno, 2002). This information overload is not present with static graphics, as information remains permanent. Besides, a series of simultaneously static graphics allows for the different states or steps within a depicted process to be consulted at any time, while an animation must be repeated as a whole (Bétrancourt et al., 2001). However, the transience of the animation could allow learners to fragment the continuous flux of visual information into chunk events, as it can be observed in “ [the participant's] attempts to anticipate upcoming information” (Boucheix & Lowe, 2010; Lowe & Boucheix, 2008, p. 270). This segmentation could then alleviate the animation-processing load.

Thus, the literature has shown that the inherent specificities of animation could be either beneficial or detrimental for the perception and the comprehension of the content to be learned. Various moderator factors have been identified as particularly influencing the instructional effectiveness of animation.

1.2. Moderator factors influencing learning from animation

The building of a coherent mental model from animations is largely determined by learners' prior knowledge and visuospatial ability, which have top-down and bottom-up influences on processing respectively (Baddeley & Hitch, 1974; ChanLin, 2001; Hegarty & Kriz, 2008; Hegarty, Canham, & Fabrikant, 2010; Kriz & Hegarty, 2004, 2007; Kalyuga, 2008; Rieber, 1991). Both factors influence how learners explore and extract visual information from the displays (Hegarty et al., 2010; Lowe, 2003). The importance of studying these two factors cannot be emphasized enough (see Hegarty & Kriz, 2008; or; Höffler, 2010), as they are an underestimated source of intrinsic differences. However, learners' individual differences are not consistently assessed in multimedia research, with a large variety of design and measurement levels (controlled or taken as covariates), as demonstrated by Höffler's meta-analysis (2010). For this reason they have not been integrated in our study.

Moderator factors focusing on the delivery features of instructional material or on the characteristics of learning tasks are as important to learning as the learners' individual characteristics, but their influences are often under-estimated. The next section details these two sets of main factors.

1.2.1. Factors related to the instructional material

The research on learning from text and static graphics has identified different functions that the visualization could fulfill relative to text information (Carney & Levin, 2002; Levin, Anglin, & Carney, 1987; Mayer, 2005) but this categorization has not been used much for animated graphics. In their meta-analysis, Höffler and Leutner (2007) adapted the categorization of Carney and Levin (2002) and distinguished representational animations from decorational ones. A decorational function translates visuals that are not directly related to the instructional purpose (Carney & Levin, 2002). Additionally, Höffler and Leutner (2007) presented inconclusive results of this moderator factor due to its confounded effect with the level of realism. Building on Ainsworth's (2008a, 2008b) view, one way to solve this issue is to consider the expressive form of representation. Subsequently, the functions of the animation could be categorized in terms of the *abstraction quality* of the visual representation dimension, as proposed by Ploetzner and Lowe (2012) in their animation's characterization. This dimension ranges from iconic to abstract representations.

As for any computer-based instruction, animations may include pacing functionalities, from simple control over the pace to advanced interactivity, defined as the possibility to interact with the content displayed. For example, Schneider (2007) provided interactivity in a device demonstrating the functioning of a pulley system in which the learners could pull the rope freely. The possibility for learners to adapt the pacing of the information stream to their comprehension capacities was found to facilitate the construction of an efficient mental model. Compared to no control or interaction mode, the pacing control over the animation was beneficial for students (Höffler & Schwartz, 2011; Mayer & Chandler, 2001; Nesbit & Adesope, 2011; Schwan & Riempp, 2004) and for children (Boucheix & Guignard, 2005). However, many other studies found that control over the pacing of the animation did not enhance comprehension (Bétrancourt & Realini, 2005; Hegarty et al., 2003; Kriz & Hegarty, 2004; Rebetez & Bétrancourt, 2007), even with novice learners (Lowe, 2003). Different explanations have been proposed but the evidence to support theses explanations is still nonexistent.

Attentional signaling or cueing may be the solution to direct learner's visual attention to crucial features and pertinent information and therefore enhance the information extraction stage and the building of an effective mental model (Schnotz & Lowe, 2008). The visual and perceptual signaling aid of cueing supplied to the learner can take on various forms, such as color-coding of elements/parts, fading of elements/parts, or added arrows. Several studies have shown that cues may improve learning by reducing the visual search to a pertinent location (e.g., Boucheix & Lowe, 2010; Mautone & Mayer, 2007; de Koning, Tabbers, Rikers, & Paas, 2010) whereas other studies have shown no influence of cueing (for instance Kriz & Hegarty, 2007).

Another factor that has received attention in the last two decades is the sensory modality in which the verbal information accompanying the visualization is conveyed. Most studies found a modality effect (Ginns, 2005; Mayer, 2005; Schmidt-Weigand, 2005) with learning being enhanced when the visualization was coupled with narration instead of written text. The usual explanation, based on Baddeley's (1993) model of a working memory with limited capacity and the cognitive load theory (Sweller, Paas, van Merriënboer, & Paas, 1998), states that distributing the processing load across two sensory channels increases working memory capacity compared to visual processing only (Moreno & Mayer, 1999; Sweller et al., 1998). However, pacing was observed to interact with modality: when the presentation was user-controlled, the modality effect vanished (Schmidt-Weigand, 2005) or even was reversed (Tabbers, 2002).

1.2.2. Factors related to the instructional context

The instructional domain (or topic) of the learning material evidently influences visual processing and subsequent learning. For instance, physics, biology, or chemistry are widely accepted to be domains benefiting from visualizations because they often require understanding complex systems, which consist of many components evolving over time. In many case, learning natural sciences requires the building of conceptual models that integrate functional, temporal, spatial, relational and causal relationships between these elements. Thus, dynamic systems are complex phenomena to understand because learners have to deal with multiple (sometimes) complementary (often) synchronous information sources. The results of Bétrancourt et al.'s review (2000) showed no systematic benefit of animation over static graphics for physics (Newton's laws of motion), biology, or informatics. In contrast, Schneider (2007) pointed out that the beneficial effects of animation were found more systematically in mathematics, physics and mechanics than in meteorology, biology and history where animation often led to no effect or a negative effect. Höffler and Leutner's (2007) meta-analysis found a larger effect for the military domain (with studies involving motor-procedural learning) than for other domains, but the observed effects were also large for chemistry. Interestingly, their meta-analysis showed that many more studies were conducted in physics than in other domains.

Two related sources of variation are the learning objectives - the type of knowledge targeted by the instructional context – and the great number of disparate tasks used to assess this knowledge acquisition. Learning objectives are multifarious. Knowledge acquisition as a specific goal of learning in multimedia literature has mainly been oriented towards the comprehension of cause-and-effect explanations. Very few studies have examined non-explanatory information, such as information describing procedural tasks or skills acquisition. Höffler and Leutner's (2007) meta-analysis raised a larger effect for procedural knowledge than for conceptual or declarative knowledge. Similarly, Ayres and colleagues demonstrated the superiority of video-based animation on the execution of hand manipulative tasks (Ayres et al., 2009), one explanation being that visualizing human movements triggers motor cortex neuronal activity. However, in his review Schneider (2007) did not find systematic benefits of animation in studies focusing on procedural knowledge and Höffler and Leutner (2007) pointed out a possible confounding effect as many visualizations with a decorational function were used to learn other types of knowledge. Another source of variation is the great number of disparate tasks used to assess learning comprehension. It varies widely across studies, from retention to far-transfer tests, from fill-in-the-blank to free-recall tests and from procedural to matching tests. Schneider (2007) underlines that within the same study the effect of animation could differ depending on the learning outcomes tested. For example, in a geographic time difference study (Schnotz, Böckheler, & Grzondziel, 1999), the comprehension test determined the advantage of the animation over the static graphics, whereas the mental simulation test showed the opposite pattern. In Lewalter's study (2003), assessments for knowledge acquisition of facts revealed no difference between static and animation learning, whereas comprehension measures showed a marginal difference in favor of animation.

To grasp a better overview of the interaction between the type of visualizations and its learning assessment, it may be appropriate to take into account a "common language about learning goals" (Krathwohl, 2002, p. 212) that is the revised version of Bloom's taxonomy (Anderson & Krathwohl, 2001; Bloom & Krathwohl, 1956; Krathwohl, 2002). This taxonomy offers a spectrum of the process of learning and identifies learning progression. This may help to distinguish between the different types of knowledge involved in knowledge acquisition in line with educational and instructional objectives. The revised version of Bloom's taxonomy (Anderson & Krathwohl, 2001) is two-dimensional, with a knowledge dimension and a cognitive process dimension. The knowledge dimension has four levels - factual, conceptual, procedural and meta-cognitive, which are organized according to their complexity. Each level is subsumed under the higher levels. The second dimension represents the six cognitive processes – remember, understand, apply, analyze, evaluate and create - activated during learning. Thus, knowing "what" (factual) is a prerequisite for knowing "how" (procedural), and the cognitive process dimension brings the granularity of the learning. Systematically referring to such taxonomy would allow a better interpretation of the many studies aiming to compare the instructional effectiveness of animation to static graphics in a multimedia learning context (Bauer-Morrison, Tversky, & Bétrancourt, 2000; Bétrancourt & Tversky, 2000; Hegarty et al., 2003; Höffler & Leutner, 2007; Moreno & Mayer, 2007; Schneider, 2007).

1.3. *Purposes of the meta-analysis*

Given these points, this summary demonstrates that multiple factors have been found or are expected to impact the potential effect of animation on learning. Literature review highlighted contradictory results reported for factors dealing with the instructional material or context. As such, no conclusive statements can be made on the instructional effectiveness of animation compared to static graphic displays. Höffler and Leutner's meta-analysis in 2007 started to address this intricate issue, by exploring seven variables as potential moderators: function of the animation, type of knowledge, instructional domain, type of animation support, level of realism, presence of accompanying text and signaling cues. In the present meta-analysis, we kept or redefined the moderators used by these authors and added two other variables extensively studied in the last decade: control over the pace, and modality of the verbal commentary (if any).

In line with the issues discussed above, the aim of this meta-analysis was to evaluate the effect of using animations compared to static visualizations in instructional material and to identify potential factors moderating this effect. Specifically, this study sought answers to the following research questions:

1. Are multimedia instructional materials containing animations overall beneficial to learning compared to static graphics display? If so, for which learning outcomes?
2. How are the animation effects influenced by factors related to the instructional material, such as the control over the pace, the function of the animation, the modality of the verbal commentary and the type of animation media?
3. How do the animation effects vary according to the instructional domain of the content to-be-learned?

2. Method

2.1. *Literature search*

Starting with the studies selected in Höffler and Leutner's study (2007), literature search was expanded and updated by a systematic search for studies published up to December 2013, comparing animated versus static graphic displays of dynamic phenomena. This was done through the PsycInfo (1806–2013), ERIC (1966–2013), Francis (1984–2013), MedLine (1950–2013) and Psyndex (1945–2013) databases. The following keywords were searched: *animation, multimedia, multimedia animation, interactive animation, static graphic, multimedia learning, dynamic picture, static picture, dynamic visualization, computer animation, interactivity.* Review studies mentioned earlier in this paper have facilitated cross-referencing of any essential study. This present meta-analysis also included studies that could be retrieved from publicly available PhD theses, unpublished at the time.

2.2. *Eligibility criteria*

Firstly, studies were primarily selected based on their abstract. Secondly, they were only included in the review when the following conditions were fulfilled: (a) the empirical study evaluated the impact of different instructional format displays, in particular a comparison of animated versus static graphic displays, (b) only expository animations, as defined in Section 1.1, designed for instructional purposes were considered, (c) only animations that were computer-based were considered, (d) the studies had to be written in English, French or German, (e) the dependent variables had to measure knowledge acquisition by the learners, and (f) the study had to provide sufficient descriptive data to calculate the effect size (if *means, standard deviations, or F* were not mentioned, we tried to contact the author to get the missing data). Based on these criteria, 73 articles were selected for this review. Thirteen articles were excluded because we did not obtain the missing information. This reduced the number of articles to 50[1] and the number of experiments to 61 (see Fig. 1). To establish the reliability of scoring procedures, 10 articles ($n_{\text{comparisons}} = 39$) were randomly selected and rescored. Interrater reliability, measured with intraclass correlation (ICC) was $r = 0.875$. The occasional discrepancy was resolved through consensus.

2.3. *Variables coded from the studies*

For each available experiment, the following eleven variables were extracted:

a) Authors and year of publication.

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[1] With respect to Höffler and Leutner's (2007) meta-analysis, 5 studies were removed: (Blake (1977), Kaiser, Profitt & Anderson (1985), Michas & Berry (2000), Spangenberg (1973–2 experiments) and Swezey (1991) as they did not match the computer-based criteria; and 41 experiments were added. The animation used in McCloskey and Kohl's study (1983) is, in our view and according to the description of their method section, computer-based, although it was firstly identified as being video-based by Höffler and Leutner.

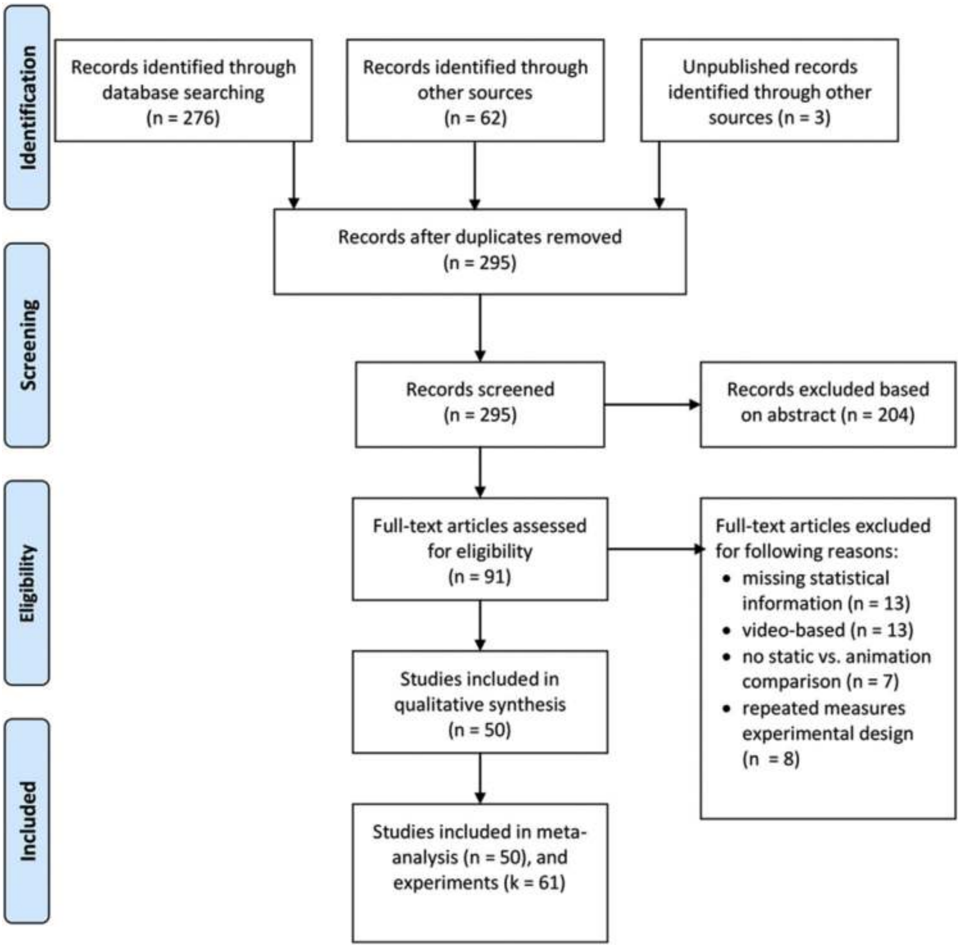

Fig. 1. PRISMA flow chart for the literature search, showing the number of studies identified, screened, found to be eligible, and then included in the meta-analysis.

b) Sample size.
c) *Instructional domain as stated by the authors* (aeronautics, astronomy, biology, chemistry, geography, geology, informatics, mathematics, mechanics, meteorology, natural sciences, physics or other).
d) *Pacing control of the display.* Four levels of pacing were differentiated: *system-paced* (the participant has no control over the pace of the display), *light* (play button only), *regular* (play and stop buttons), and *full* (paced level plus rewind, fast-forward buttons and multiple viewings possible).
e) *Presence of signaling cues*, provided with arrows, color-coding, or fading (*yes, no, no data available*).
f) *Abstraction of the visual representation (function) of the animation inferred from study snapshot examples.* Based on the characterization of expository animations proposed by Ploetzner and Lowe (2012), two levels of *the abstraction quality* of the visual representations were distinguished, namely *iconic representation,* which includes schematic pictures, realistic pictures, and photo-realistic pictures; and *abstract representation,* which includes analytical pictures, formal notation, symbols, charts, diagrams, graphs, and maps.
g) *Modality of the commentary accompanying the displays* (animation and static graphics). According to the available information in the study, differentiation of the accompanying commentary modalities was made between *visual* (*written text*), auditory (*narration*), *written text available on separate pages*, *no text,* and *no data available.* When modalities differed between the 2 displays, they were labeled "*different*".
h) *Form of the outcomes variates and their statistical values.* For this analysis, only tests assessing knowledge acquisition were examined. Knowledge acquisition assessment must be understood as learning outcome(s), coming from the multifarious forms of retention and comprehension measured by the authors trained during the learning/study phase of the study. We listed 14 different types of learning tests in the selected studies, such as *retention, inference, near and far*

transfer, multiple choice questionnaire, comprehension, problem solving, fill in the blanks, drawing, descriptive learning, free recall, procedural, preferences and matching tests.

i) *Recoding of the outcomes variates according to the Bloom's revised taxonomy.* Considering the wide range of outcomes assessment (h) used in this meta-analysis, one would be entitled to question whether the various comprehension tests were measuring the learner's knowledge comprehension. Though some consistency appeared in the global paradigm used in these studies, the learning tests were made up ad hoc for each study, with little agreement on which indicators can be considered as valid to assess comprehension. Although the validity and the fidelity of the "home-made" tests are not questioned, it is difficult to compare the outcomes of these studies, particularly the comprehension level, and to categorize it based on the cognitive processes involved. The use of a pedagogical model as standard knowledge acquisition criteria may be interesting due to its classification of knowledge acquisition levels. From the many pedagogical models and taxonomies defined in literature, Bloom's revised taxonomy (Anderson & Krathwohl, 2001) was chosen to recode the outcomes variates (h) because it highlights the link between knowledge and cognitive abilities. This revised taxonomy may be seen as a double-entry table, where the six-level cognitive dimension (*remember, understand, apply, analyze, evaluate* and *create*) crosses the knowledge dimension (*factual*, *conceptual*, *procedural* and *meta-cognitive* knowledge*)*. The intersection of each entry translates the cognitive process involved in the learning procedure, or in other words how the cognitive depths interact with different types of knowledge (see Bloom (1971) and Anderson and Krathwohl (2001) for more details on the taxonomy).

2.4. *Calculation of effect sizes*

Each outcome was reported as an independent statistical value. The effect sizes (ES) measures for two independent groups (animated versus static graphics) were calculated from means and standard deviations directly reported in the studies, except in 11 comparisons that were based on *F* statistics or on *Chi* statistics for 2 of them. Lipsey and Wilson's (2001) formulas were used to compute effect sizes from other statistics than means and SD. The effect sizes were computed as Hedges's *g* (standardized mean difference effect size) based on standardized difference, which defines a variation on Cohen's *d*, (Lipsey & Wilson, 2001). The choice of Hedges's *g* was made in order to uniform (standardize) the variety of different psychometric scales used to assess the outcomes in studies. Hedges's *g* formula of effect size, $ES_{\mathrm{sm}} = [(\mathrm{M}_{\mathrm{anim}} - \mathrm{M}_{\mathrm{static}})/(\mathrm{S}_{\mathrm{pooled}})^2]$ is defined as the square root of the average of the squared standard deviations. A bias correction for small sample sizes was adopted as: $g = [1 - (3/(4N\text{-}9))]\mathrm{ES}_{\mathrm{S.}}$ To avoid an over representation of large sample sizes, the *ES* was weighted by the inverse of standard error (Lipsey & Wilson, 2001). The assumption of independence, central for the meta-analysis approach, is that the effects are independent of one another. However, to avoid violating this assumption, when studies reported multiple outcomes, a decision was made to treat them as independent estimates. This option will affect the statistical analyses in that the standard error for the point estimate computed across the multiple outcomes will likely be erroneously small (Borenstein, Hedges, Higgins, & Rothstein, 2009). This partial violation of assumptions of the statistical method was regarded as less severe than the loss of important information, which the analysis would have otherwise suffered. The outliers were detected according to Huffcutt & Arthur's procedure (cited by Lipsey & Wilson, 2001), which determined them as a break in the effect size distribution. Inspection of the *ES* indicated 4 outliers, ($g = 4.62$, $g = 3.47$, $g = -1.91$ in ChanLin's study (2001), and $g = 3.59$ in Yang et al.'s study (2003)), which were more than ± 2 SD from the global *ES*. The outliers were brought back to the less extreme value, which was 2.03 for positive values and - 1.08 for negative values. The variability of the overall effect sizes was tested with a homogeneity analysis, a *Q* statistics, which has a χ^2 (Chi square) distribution (Cooper, 1989; Hedges & Olkin, 1985). A significant *Q* allows further explorations, i.e., subgrouping analyses, moderators' analyses. I^2 statistics was also computed in order to describe the percentage of variability in a set of *ES* due to true heterogeneity, which is the between-studies variability. I^2 formula ($I^2 = 100\%$ x $(Q\text{-df})/Q$) was used to express the inconsistency of studies' results (Borenstein et al., 2009). From a conventional usage, a positive value of the effect size *g* demonstrates the benefits of the effectiveness of animations over static graphics.

2.4.1. *Tests for subsequent analyses*

The subsequent analyses were performed using a random-effects model within group analysis. The random-effect model assumes that each study is associated with a different but related parameter (Borenstein, Hedges, & Rothstein, 2007; Borenstein et al., 2009; Normand, 1999). The procedure of this model is that each comparison is weighted by the inverse of the sampling variance plus a constant that represents the variability across the population effects (Wilson, 2006). A moderator analysis separates Q into various components. Goodness-of-fit, which consists of a between-group Chi square, namely Q_B, was computed in order to describe variation within the subgroups. This statistic, if $Q_B < p = .05$, indicates that the *ES* significantly varies as a function of the moderator (Borenstein et al., 2009; Cooper, 1989; Lipsey & Wilson, 2001).

To account for the possibility that the present meta-analysis missed non-significant results, the fail-safe *N* (Rosenthal, 1979), which reflects the number of unpublished studies needed in order to lower the effect size estimate to nonsignificant, was calculated. The bias of publication was evaluated with the fail-safe *N* procedure. The calculations of the standardized mean difference effect sizes (Hedges's *g*) and the random-effect model were computed and analyzed with the CMA© (Comprehensive Meta Analysis) software.

3. Results

3.1. Descriptive results

One hundred and forty effects (140) derived from 61 between-group experiments were extracted from these articles (see Appendix, Table A1, for the specific characteristics of the pair-wise comparisons). The total number of participants across the studies was 7036.

A detailed analysis of the 140 pair-wise comparisons showed that animations were superior to static graphic displays in 43 comparisons (30.7%), whereas 14 (10%) were in favor of static illustrations, and 83 (59.3%) found no significant difference between these two format presentations. Within the no-significant results, 13 comparisons (15.6%) showing distinct patterns depending on learners' individual abilities, such as prior knowledge levels or spatial ability, were found.

Very few articles mentioned the correspondence between their dependent variable outcomes and a standard knowledge criterion. Gagné's taxonomy (1982) was mentioned by Rieber (1989, 1991), and Bloom's taxonomy (1956) was mentioned by Rigney (1976). Wang, Vaughn, and Liu (2011) referred to the revised taxonomy of Bloom (Anderson & Krathwohl, 2001). Recoding the initial learning outcomes with the BTr (Anderson & Krathwohl, 2001) has reduced the number of outcomes variates from 13 to 8, as can be seen in Table 1.

3.2. Analysis of effect sizes (ES)

The overall Hedges's *g* effect size showed a significant value 0.226 ($p = < 0.001$, 95% confidence interval (CI_{95}) 0.12–0.33). According to Cohen's rule of thumb (1988), the overall ES has a small magnitude. This positive effect size indicates an advantage associated with animations, what we refer to as an animation effect, and suggests that studying with animation when learning dynamic phenomena is beneficial compared to static graphic displays. The overall test for homogeneity indicated heterogeneity across samples ($Q = 643.18$, df = 139, $p < 0.001$; $I^2 = 78.38$). Moreover, I^2 showed a high heterogeneity, 78%, indicating that one or more moderator characteristics, other than sampling error or chance, might account for this heterogeneity. Regarding whether the observed overall Hedges's *g* effect size is biased, a publication bias may be excluded since the fail-safe *N* (Rosenthal, 1979) is 2999. This suggests that it would be necessary to locate and include 2999 studies averaging an effect size of zero for the effect size to be insignificant.

Up until this point, the animation effectiveness was established as significant, but the effect is rather small. Subgroup analyses were conducted for the multiple dependent variables – recoded with the Bloom revised taxonomy. Effect sizes and confidence intervals are given in Table 2. With regards to the knowledge dimension, it is clear that animations were more effective than static graphics for learning factual ($g = 0.336$, $Z = 3.229$, $p = .001$) and conceptual knowledge ($g = 0.162$, $Z = 2.722$, $p = .006$). However, there was no evidence that the impact of learning with animation varied by knowledge dimensions ($Q_B = 2.535$, *n.s*). Similarly, learning with animation was associated with statistically detectable effect sizes when cognitive processes, such as remembering ($g = 0.205$, $Z = 1.923$, $p = 0.054$), understanding ($g = 0.198$, $Z = 2.436$, $p = 0.015$), or applying ($g = 0.333$, $Z = 3.741$, $p < 0.001$), were involved. The between-levels difference (Q_B) was not significant. This suggests that the effects of learning with animations were positive regardless of whether the cognitive processes involved are remembering, understanding, applying, or analyzing. The crossed dimensions analysis revealed that learning with animations is more beneficial than static graphics when factual knowledge has to be remembered ($g = 0.392$, $Z = 2.551$, $p = 0.011$) or understood ($g = 0.280$, $Z = 1.969$, $p = 0.049$), or when conceptual knowledge has to be understood ($g = 0.179$, $Z = 1.945$, $p = 0.052$), or applied ($g = 0.232$, $Z = 2.838$, $p = 0.005$). There is no evidence that the impact of learning with animation varies by crossed dimension ($Q_B = 4.288$, *n.s*).

3.3. Does the effect of studying with animations vary? moderators' analyses

To determine the conditions under which studying with animations may enhance or inhibit learning, moderators' analyses were conducted and the results are presented in Table 3. These were organized by two sets of factors, instructional material and instructional domains.

3.3.1. The role of instructional material factors

Table 3 presents the effect sizes of instructional material factors. Most of the comparisons (96) were system-paced. There is evidence that the pacing control of the display had a significant effect on the animation effect ($Q_B = 8.921$, $p = 0.003$). The

Table 1
Number of pair-wise comparisons of the sample falling into each category of the learning outcomes as defined in the Bloom's revised taxonomy (Anderson & Krathwohl, 2001).

Knowledge levels	Cognitive processes dimensions			
	Remember	Understand	Apply	Analyze
Factual	16	16		
Conceptual	16	52	22	3
Procedural		9	6	

Table 2

Summary of the outcomes' *ES* when grouping based on Bloom's Taxonomy, according to a random-effect model analysis. The mean Hedges's g, the 95% Confidence Intervals, Q_B and k are shown.

Bloom taxonomy revised	Effect size		95% CI	Test of heterogeneity			k
	g	SE		Q_B	df	p	
Knowledge dimension							
Factual	0.336[a]	0.104	[0.132; 0.540]				32
Conceptual	0.162[a]	0.060	[0.045; 0.279]				93
Procedural	0.387	0.273	[−0.148; 0.921]				15
Between levels				2.535	2	0.28	
Cognitive processes dimension							
Remember	0.205Δ	0.106	[−0.004; 0.414]				32
Understand	0.198[a]	0.081	[0.039; 0.358]				77
Apply	0.333[a]	0.089	[0.159; 0.508]				28
Analyze	0.219	0.390	[−0.545; 0.984]				3
Between levels				1.454	3	0.69	
Crossed dimensions							
Remember factual kn.	0.392[a]	0.154	[0.091; 0.694]				16
Understand factual kn.	0.280[a]	0.142	[0.001; 0.559]				16
Remember conceptual kn.	0.017	0.136	[−0.249; 0.284]				16
Understand conceptual kn.	0.179 Δ	0.092	[−0.001; 0.359]				52
Apply conceptual kn.	0.232[a]	0.082	[0.072; 0.392]				22
Analyze conceptual kn.	0.219	0.390	[−0.545; 0.984]				3
Understand procedural kn.	0.351	0.387	[−0.407; 1.109]				9
Apply procedural kn.	0.444	0.406	[−0.352; 1.240]				6
Between levels				4.288	7	0.74	

[a] Significant $p < .05$; Δ marginally significant ($p < .06$); kn. = knowledge; k = number of pairwise comparisons.

effect size when learning is system-paced, that is to say when learners had no control over the pace of the display, was statistically different from zero ($g = 0.309$, $Z = 4.637$, $p < 0.001$), and was associated with a medium effect size. The effect sizes of the three other pacing control modalities (light, regular and full) were not significant.

The presence ($g = 0.204$, $Z = 1.870$, $p = 0.060$) or absence of cueing ($g = 0.198$, $Z = 2.979$, $p = 0.003$) was associated with statistically detectable effect sizes. However, the between-level difference was not significant ($Q_B = 0.463$, *n.s*), suggesting that the effects of learning with animations were positively identical regardless of whether signaling cues were provided or not.

With respect to the abstract quality of the visual representation, results indicate that the animation effect differs by types of representations ($Q_B = 6.357$, $p = 0.042$). While ignoring the "no data available" subgroup, the effect size within the iconic representations subgroup is statistically different from zero ($g = 0.245$, $Z = 3.598$, $p < 0.001$), and was associated with a small effect size.

Regarding the sensory mode of the accompanying verbal information, there is evidence that the animation effect differs by type of sensory modes ($Q_B = 22.230$, $p < 0.001$). Only the effect sizes within the subgroups *no additional textual information* ($g = 0.883$, $Z = 3.947$, $p < 0.001$) or *narration* ($g = 0.336$, $Z = 3.986$, $p < 0.001$) were statistically different from zero, and were associated with a large and medium animation effect, respectively.

3.3.2. *The role of learning context*

Table 3 presents the results of the instructional domains, which showed a significant animation effect ($Q_B = 32.245$, $p = 0.001$). A large effect size was observed when studying natural phenomena ($g = 1.260$, $Z = 4.433$, $p < 0.001$), a medium one for chemistry ($g = 0.773$, $Z = 2.987$, $p = 0.003$), while studying biology ($g = 0.202$, $Z = 3.254$, $p = 0.001$) was associated with a small effect size. The effect sizes of the other instructional domain modalities were not significant.

4. Discussion

The present meta-analysis had two main objectives: Firstly, to assess whether animation was beneficial overall to learning compared to static graphics, and for which learning outcomes. Secondly, in order to deepen our understanding of the beneficial use of animation in instructional materials, this analysis aimed at identifying the moderating factors affecting the global overall effect. This was grouped along two dimensions: instructional material, and instructional domains. We will discuss our findings regarding these two issues.

4.1. *What are the effects of learning with animations compared to static graphics?*

The analysis of 140 pair-wise comparisons from the 61 studies taken into account indicated a weighted mean effect size of $g = 0.226$ (95% CI 0.12–0.33), which can be considered of small magnitude according to Cohen's rule of thumb (1988). As expected, studying with animated visualizations yields higher learning gains than studying with static graphics. With more than 7000 subjects included in this meta-analysis, the generalization of this study can be considered stable. This study thus

Table 3

Moderators' ES analyses. The mean of the standardized mean difference (Hedges's g), the 95% Confidence Interval, Q_B and k are shown.

Moderators	Effect size		95% CI	Test of heterogeneity			k
	g	SE		Q_B	df	p	
Pacing control of the display							
System-paced	0.309[a]	0.067	[0.179; 0.440]				96
Light	0.129	0.133	[−0.132; 0.390]				17
Regular	0.061	0.129	[−0.192; 0.314]				15
Full	−0.120	0.146	[−0.407; 0.166]				12
Between levels				8.921	3	0.03	
Cueing							
Presence of cueing	0.204Δ	0.109	[−0.010; 0.417]				53
No cueing	0.228[a]	0.065	[0.101; 0.356]				68
No data available	0.271[a]	0.093	[0.088; 0.454]				19
Between levels				0.243	2	0.886	
Abstraction quality of the animation							
Abstract repr.	0.006	0.093	[−0.176; 0.188]				26
Iconic repr.	0.245[a]	0.068	[0.112; 0.378]				91
No data available	0.365[a]	0.131	[0.108; 0.623]				23
Between levels				6.357	2	0.042	
Sensory mode of the commentary accompanying the animation							
Visual (written)	0.105	0.080	[−0.051; 0.262]				58
Auditory (narration)	0.320[a]	0.084	[0.171; 0.501]				28
Different	0.157	0.126	[−0.091; 0.405]				30
No textual info	0.886[a]	0.224	[0.445; 1.322]				14
No data available	−0.115	0.104	[−0.318; 0.089]				10
Between levels				22.740	4	<0.0001	
Instructional domains							
Aeronautics	−0.004	0.206	[−0.409; 0.400]				4
Astronomy	0.269	0.157	[−0.038; 0.576]				4
Biology	0.202[a]	0.062	[0.080; 0.323]				33
Chemistry	0.773[a]	0.259	[0.266; 1.281]				8
Geography	0.232	0.658	[−1.057; 1.521]				2
Geology	−0.102	0.336	[−0.761; 0.558]				4
Informatics	0.108	0.123	[−0.133; 0.349]				13
Mathematics	−0.067	0.180	[−0.420; 0.286]				11
Mechanics	−0.106	0.014	[−0.339; 0.127]				22
Meteorology	0.312	0.209	[−0.098; 0.722]				9
Natural sciences	1.260[a]	0.284	[0.703; 1.817]				8
Other	0.134	0.270	[−0.394; 0.663]				8
Physics	0.431	0.269	[−0.096; 0.958]				14
Between levels				32.245	12	0.001	

[a] Significant $p < 0.05$; Δ marginally significant ($p < .06$), k = number of pairwise comparisons.

confirms and supports the findings of a previous meta-analysis conducted by Höffler and Leutner (2007), who found an overall small-to-medium positive effect of animation of $d = 0.37$. The smaller effect size in our meta-analysis can be explained by the inclusion of 41 additional experiments in the analysis as well as the higher percentage of pair-wise comparisons (10% compared to 2.6%) favoring static graphics. It is important to note that, although the meta-analysis showed the overall beneficial effect of animation, only 30.7% of the comparisons raised significant differences in favor of animation and 59.3% found no significant differences. The decision to exclude 7 video-based studies from the present meta-analysis, representing 12 pair-wise comparisons in Höffler and Leutner's study, suggests an alternative explanation for this discrepancy. Indeed, the definition of the term animation used in this present work (see 1) excludes video-based studies, as video "refers to a motion of picture depicting movement of real objects" (Mayer & Moreno, 2002, p. 88). These results definitely call for further examination of moderating variables. By considering the moderating conditions, a comprehensive interpretation of this overall effect size can be established.

4.1.1. How do animation effects vary with different learning outcomes?

The learning outcomes were recoded using Bloom's revised taxonomy (Anderson & Krathwohl, 2001), from which we retained three types of knowledge (factual, conceptual, and procedural) and four cognitive processes (remembering understanding, applying, and analyzing). The meta-analysis revealed that animation was significantly more effective than static graphics for learning factual and conceptual knowledge on the one hand, and for the cognitive activities of remembering, understanding and applying on the other hand. The interaction of cognitive depths with the types of knowledge showed that studying with animation rather than with static graphics was more effective for the levels of remembering or understanding factual knowledge as well as understanding or applying conceptual knowledge. However, none of the differences between these subgroupings reached significance, meaning that there was no evidence that the effect of animation varies by type of requested knowledge, cognitive process or crossed dimension. These findings differ from the ones of Höffler and Leutner

(2007), who showed a significantly greater effect size for procedural-motor knowledge than for declarative and conceptual knowledge. Several explanations could be proposed to shed light on these discrepant results. First of all, a possible sampling issue has to be considered. This present analysis took into account a substantial number (41) of additional studies, and excluded 7 studies reporting video-based experiments. Another probable explanation may depend on our deliberate choice to use Bloom's revised taxonomy, in order to contain the diversity of the learning objectives' measures. Indeed, researchers conceal behind the labels "retention" or "comprehension" a full range of learning goals. Using Bloom's revised taxonomy enabled us to obtain a common basis for comparison, while standardizing learning objectives across all studies. While Höffler and Leutner included 5 comparisons for procedural knowledge, this meta-analysis included 16 comparisons. It considered Anderson and Krathwohl's (2001) definition of procedural knowledge, which included cognitive as well as motor procedural knowledge, as the explanation for the presence of the *procedural-understand* crossed category. Additionally, it could not be excluded that confounding factors might have reduced the animation effect.

4.2. How are animation effects influenced by factors related to the instructional material?

Four factors related to the instructional material were taken into account as moderators: pacing control of the display, signaling cues, abstraction of the visual representation and modality of accompanying commentary.

An important but surprising finding of this meta-analysis is that the positive effect of animation over static graphics was found only for system-paced instructional material, or in other words when learners did not control the pace of the display. Whereas research reported inconsistent findings, with some studies showing a benefit of control (Boucheix & Guignard, 2005; Mayer & Chandler, 2001; Schwan & Riempp, 2004), these findings are in line with other studies that found no benefit (for example Adesope & Nesbit, 2012). As such, the system-paced presentation, together with the transient nature of animation, frequently seen as a drawback, did not impede learners to study the current information and images while integrating the previous learning content (Moreno & Mayer, 2007). However, it is highly probable that the effect of pacing control interacts with other factors, such as learners' cognitive style (Höffler & Schwartz, 2011), prior knowledge, learning objectives, and/or modality of the accompanying information (Schmidt-Weigand, 2005; Tabbers, 2002).

The moderating value of cueing implemented in several experiments now comes into question. Results showed that the average effect size of the presence or absence of signaling cues did not differ significantly, suggesting that this moderator does not provide persuasive evidence about whether cueing moderates the overall animation effect. At first glance, this is not consistent with the growing evidence of visual cues improving learning in literature (Boucheix & Lowe, 2010; de Koning et al., 2010; Lin & Atkinson, 2011; Mautone & Mayer, 2007; to only name few). However, some studies demonstrated that cueing could also counteract spontaneous exploration and add extraneous visual information (Boucheix, Lowe, Putri, & Groff, 2013). Another plausible explanation may stem from the expository characteristic of the animated visualizations included in this meta-analysis. This eligibility criterion was selected to follow Ploetzner and Lowe's (2012) recommendation to compare research on learning from animations. The expository purpose "intend [s] to provide an explicit explanation of the entities, structures, and processes involved in the subject matter to be learner" (Ploetzner & Lowe, 2012, p. 782). It may therefore be that "well-designed" expository animations are self-sufficient to draw learners' attention to the right place at the right time. This hypothesis bears further investigation in the multimedia research that has largely overlooked factors related to the instructional design of the visualization.

Interestingly, the abstraction quality of the visual representations, coded using the characterization proposed by Ploetzner and Lowe (2012), was clearly identified as a moderating factor, not considering the unavailable data comparisons. In the present meta-analysis, only the animated visualizations coded as iconic produced a small and positive animation effect. Following the distinction proposed by Ploetzner and Lowe (2012) (see 2.3), iconic representations resemble the object they depict with respect to shape, texture, color or other visual details, by contrast with abstract representations that use space and visual information to represent symbolic dimensions (time, quantity, etc.). At first glance, our findings may seem inconsistent with the cognitive load theory (Chandler & Sweller, 1991) as well as with the multimedia learning theory of Mayer (Mayer, 1997, 2001), which both predict that realistic representations impede learning. Indeed the large number of visual details included in realistic representations, be they relevant or extraneous for learning, might be more challenging for learners to detect and memorize the information necessary for understanding. Several studies demonstrated that highly realistic pictures were less effective than less realistic ones (Imhof, Scheiter, & Gerjets, 2007; Kühl, Scheiter, & Gerjets, 2012; Scheiter, Gerjets, Huk, Imhof, & Kammerer, 2009). However, these studies focused on the level of realism for pictorial representations ranging from highly schematic to photo-realistic, which were all coded in the same – iconic – category in the present meta-analysis. Although the distinction between iconic vs. abstract visualizations proposed by Ploetzner and Lowe (2012) makes sense, it refers to different semiotic systems, respectively pictorial and symbolic. In this respect our findings call for further refining beyond these two categories.

Moreover, it should be noted that a medium and positive animation effect was found in the studies that could not be classified, as snapshots or detailed descriptions of the visual representations were not available or missing in the articles. Overall, these findings highlight the importance of considering of the semiotic characteristics of the representations that was largely overlooked in the multimedia literature so far (Imhof et al., 2007; Ploetzner & Lowe, 2012; Schnotz & Lowe, 2003).

The analysis of the sensory modality of the accompanying information showed a strong animation effect when no accompanying information was presented with the animation, and a moderate effect when verbal information was conveyed through the auditory mode. This latter case, also known as "modality principle" (Mayer & Moreno, 1998; Mayer, 2001;

Moreno & Mayer, 1999), is in line with the large body of research showing that verbal information should be displayed in auditory mode since it offloads the visual processing channel that can then be allocated to the deep processing of the visual material (for a review, see Ginns, 2005). More surprising is the large positive animation effect when the instructional material did not include any accompanying textual information. This result suggests that animation, by providing a progressive presentation of the content and a direct visualization of change over time (Tversky et al., 2002), is an effective medium to convey certain type of content that further research should better identify. It also confirms that using animation as sole source of learning is relevant and can prevent from split attention or cognitive overload effects.

4.3. How does the animation effect vary according to the instruction domain?

The instructional domain was identified on the basis of the content topic conveyed in the visualization. Three domains, namely natural sciences, chemistry and biology, induced respectively a strong, medium and small beneficial animation effect. These domains were associated with greater learning gains when studying was made with animations than with static graphics. However, we may doubt that the instructional domain per se is cognitively valid as a moderating variable. Instructional domains cannot be isolated from the educational objectives, nor from the required tasks, level of abstraction, type of knowledge and cognitive processing, which all vary as widely within domains as between them. Following Ainsworth's (2008b), the research should search for a better “differentiat [ion] between learners understanding of representations and the way they encode domain” (p. 7).

4.4. Limitations of the present meta-analysis

This meta-analysis used specific search criteria and included studies in three languages (English, German, and French), including studies that were not published at the time, but were publicly available, namely PhD theses. However, some studies necessarily eluded the search, since no sampling can be exhaustive. As a result, we had very few comparisons for some moderating variables, and this lowered the statistical power of results.

Moreover, we encountered the greatest difficulty in assessing types of learning outcomes. The categorization of learning outcomes turned out to be very difficult since under the terms of retention or comprehension lay multiple and diverse dependent variables in the literature. In particular, some assessment tests included graphical items, while others were only verbal, which is not accountable when using Bloom's revised taxonomy. The use of text-based categories (i.e., retention inference) does not account for the specificity of multimedia material. With regards to the type of visual representation, and paradoxically for a field interested in graphic illustration, in many cases there were only a few descriptions of the instructional material, and 16.4% provided no picture at all of the material used. Therefore, coding for these two categories is somehow debatable, or at least not optimally suited, even if the two judges agreed quite well on the classification.

Regarding the statistical analyses, the power for comparing subgroups is often very low (Hedges and Pigott, 2004; cited by Borenstein et al., 2009). The unequal number of studies per subgroups may have limited the power to detect significant moderator variables and subgroup modalities. However, one should not assume that the moderators and/or their subgroupings are unimportant.

5. Conclusion

While the present meta-analysis showed the overall positive effect of studying with animations compared to static graphics, it also showed that several factors acted as significant moderators, which explains why most studies could not find the significant benefit of animation over static graphics. Level of control is a promising issue for future research in terms of how they affect exploration and comprehension processes.

Concretely, research on instructional animation and more generally multimedia could clearly facilitate the generalization of results with an agreement on learning assessment methodology. Finally, an effort should be made to better describe our visualizations in papers, whether static or animated, for example when establishing a specific categorization of functional and semiotic roles of animation in instructional material.

With that in mind, we strongly believe that animation research is now capable of answering the fundamental questions of when and why animation is beneficial (Hegarty, 2004a) and to whom (Höffler, 2010), provided that the studies address not only learning outcomes but also on-line processes.

Appendix

Table A1. Specific characteristics of the 140 pair-wise comparisons included for meta-analysis, derived from 61 experiments

Study	Hedges' s g	Bloom revised taxonomy		Instructional domain	Control presence	Sensory mode of commentary	Cueing	Visual representation	Included in Höffler and Leutner (2007)
		Knowledge dimension	Cognitive dimension						
Adesope and Nesbit (2013)	0.167	Factual	Remember	Biology	Light	Narration	No	Abstract repr.	No
Adesope and Nesbit (2013)	0.213	Conceptual	Apply	Biology	Light	Narration	No	Abstract repr.	No
Adesope and Nesbit (2013)	0.336	Conceptual	Understand	Biology	Light	Narration	No	Abstract repr.	No
Baek and Layne (1988)	0.357	Conceptual	Understand	Informatics	Full	Written	n/a	Abstract repr.	Yes
Beijersbergen & van Oostendorp (2007)	0.079	Conceptual	Remember	Mechanics	None	Written	No	Iconic repr.	No
Beijersbergen & van Oostendorp (2007)	−0.413	Conceptual	Understand	Mechanics	None	Written	No	Iconic repr.	No
Beijersbergen & van Oostendorp (2007)	0.201	Factual	Remember	Mechanics	None	Written	No	Iconic repr.	No
Beijersbergen & van Oostendorp (2007)	−0.055	Conceptual	Remember	Biology	None	Written	No	Iconic repr.	No
Beijersbergen & van Oostendorp (2007)	−0.955	Conceptual	Understand	Biology	None	Written	No	Iconic repr.	No
Beijersbergen & van Oostendorp (2007)	−0.168	Factual	Remember	Biology	None	Written	No	Iconic repr.	No
Bétrancourt, Dillenbourg, and Clavien (2008)	0.758	Conceptual	Understand	Meteorology	Light	Narration	Yes	Iconic repr.	No
Bétrancourt et al. (2008)	0.357	Factual	Understand	Meteorology	Light	Narration	Yes	Iconic repr.	No
Blankenship and Dansereau (2000)	0.549	Conceptual	Remember	Informatics	None	Written	No	Iconic repr.	No
Blankenship and Dansereau (2000)	0.794	Factual	Remember	Informatics	None	Written	No	Iconic repr.	No
Byrne, Catrambone, and Stasko (1999) expe 1	0.335	Conceptual	Apply	Informatics	None	n/a	no	Abstract repr.	No
Byrne et al. (1999) expe 1	−0.067	Conceptual	Understand	Informatics	None	n/a	No	Abstract repr.	No
Byrne et al. (1999) expe 2	−0.313	Conceptual	Understand	Informatics	None	n/a	No	Abstract repr.	No
Byrne et al. (1999) expe 2	0.107	Procedural	Apply	Informatics	None	n/a	No	Abstract repr.	No
Catrambone and Seay (2002) expe 2[A]	−0.120	Conceptual	Apply	Informatics	Full	Different	No	Abstract repr.	Yes
Catrambone and Seay (2002) expe 2[A]	−0.049	Conceptual	Understand	Informatics	Full	Different	No	Abstract repr.	Yes
ChanLin (1998)	0.466	Factual	Understand	Biology	None	Written	No	Iconic repr.	Yes
ChanLin (1998)	−0.470	Procedural	Understand	Biology	None	Written	No	Iconic repr.	Yes
ChanLin (1998)	−0.003	Factual	Understand	Biology	None	Written	No	Iconic repr.	Yes
ChanLin (1998)	0.171	Procedural	Understand	Biology	None	Written	No	Iconic repr.	Yes
ChanLin (2001)	4.621[B]	Factual	Understand	Physics	None	Written	Yes	Iconic repr.	Yes
ChanLin (2001)	3.472[B]	Procedural	Understand	Physics	None	Written	Yes	Iconic repr.	Yes
ChanLin (2001)	−0.230	Factual	Understand	Physics	None	Written	yes	Iconic repr.	Yes
ChanLin (2001)	−1.910[C]	Procedural	Understand	Physics	None	Written	Yes	Iconic repr.	Yes
Craig, Gholson, and Driscoll (2002)	0.592	Conceptual	Apply	Meteorology	None	Narration	No	Iconic repr.	Yes
Craig et al. (2002)	0.411	Conceptual	Understand	Meteorology	None	Narration	No	Iconic repr.	Yes
Craig et al. (2002)	0.883	Factual	Remember	Meteorology	None	Narration	No	Iconic repr.	Yes
Craig et al. (2002)	1.294	Factual	Understand	Meteorology	None	Narration	No	Iconic repr.	Yes
Dubois and Tajariol (2001)	0.300	Conceptual	Apply	Aeronautics	None	Written	Yes	n/a	No
Dubois and Tajariol (2001)	−0.051	Conceptual	Remember	Aeronautics	None	Written	Yes	n/a	No
Dubois and Tajariol (2001)	−0.469	Conceptual	Understand	Aeronautics	None	Written	Yes	n/a	No
Dubois and Tajariol (2001)	0.194	Factual	Remember	Aeronautics	None	Written	Yes	n/a	No
Hays (1996)	0.366	Conceptual	Understand	Biology	None	Written	n/a	n/a	Yes
Hays (1996)	−0.323	Factual	Understand	Biology	None	Written	n/a	n/a	Yes
Hays (1996)	0.614	Conceptual	Understand	Biology	None	Written	n/a	n/a	Yes
Hays (1996)	0.406	Factual	Understand	Biology	None	Written	n/a	n/a	Yes
Hegarty et al. (2003) expe 1	1.187	Conceptual	Remember	Mechanics	System-paced	Different	Yes	Iconic repr.	No
Hegarty et al. (2003) expe 1	0.498	Conceptual	Understand	Mechanics	system-paced	Different	Yes	Iconic repr.	No
Hegarty et al. (2003) expe 2	−0.351	Conceptual	Remember	Mechanics	System-paced	Different	Yes	Iconic repr.	No
Höffler (2003)	−0.160	Conceptual	Understand	Biology	System-paced	Written	Yes	Iconic repr.	Yes
Höffler (2003)	−0.209	Factual	Understand	Biology	System-paced	Written	Yes	Iconic repr.	Yes
Höffler and Leutner (2011) expe 1	0.703	Conceptual	Understand	Chemistry	None	Narration	No	Iconic repr.	No
Höffler and Leutner (2011) expe 2	0.412	Conceptual	Understand	Chemistry	None	Narration	No	Iconic repr.	NO
Höffler, Prechtl, and Nerdel (2010)	−0.192	Conceptual	Understand	Biology	None	Written	Yes	Iconic repr.	No

Höffler et al. (2010)	−0.139	Factual	Understand	Biology	None	Written	Yes	Iconic repr.	No
Kalyuga (2008)	0.468	Conceptual	Apply	Mathematics	None	No textual info	Yes	Abstract repr.	No
Kalyuga (2008)	−1.008	Conceptual	Apply	Mathematics	None	No textual info	Yes	Abstract repr.	No
Kühl et al. (2012)	1.236	Conceptual	Understand	Natural Sciences	None	No textual info	Yes	Iconic repr.	No
Kühl et al. (2012)	2.019	Conceptual	Understand	Natural Sciences	None	No textual info	Yes	Iconic repr.	No
Kühl et al. (2012)	2.108	Factual	Remember	Natural Sciences	None	No textual info	Yes	Iconic repr.	No
Kühl et al. (2012)	1.265	Factual	Remember	Natural Sciences	None	No textual info	No	Iconic repr.	No
Kühl et al. (2012)	1.419	Procedural	Apply	Natural Sciences	None	No textual info	No	Iconic repr.	No
Kühl et al. (2012)	1.883	Procedural	Apply	Natural Sciences	None	No textual info	No	Iconic repr.	No
Lai (2000)	−0.019	Conceptual	Apply	Informatics	None	No textual info	Yes	Abstract repr.	Yes
Lewalter (2003)	0.596	Conceptual	Apply	Physics	None	Different	Yes	Iconic repr.	Yes
Lewalter (2003)	0.004	Factual	Remember	Physics	None	Different	Yes	Iconic repr.	Yes
Lin and Atkinson (2011)	0.256	Conceptual	Remember	Natural Sciences	None	Narration	Yes	Iconic repr.	No
Lin & Atkinson (2010)	0.062	Conceptual	Understand	Natural Sciences	None	Narration	Yes	Iconic repr.	No
Lowe (2003)	−0.343	Procedural	Apply	Meteorology	Light	n/a	No	Abstract repr.	No
Marbach-Ad, Rotbain, and Stavy (2008)	0.562	Conceptual	Apply	Biology	None	Different	No	Iconic repr.	No
Marbach-Ad et al. (2008)	0.198	Conceptual	Understand	Biology	None	Different	No	Iconic repr.	No
Mayer, Deleeuw, and Ayres (2007), expe 1	−0.203	Conceptual	Remember	Mechanics	None	Different	Yes	Iconic repr.	No
Mayer et al. (2007) expe 1	−0.123	Conceptual	Understand	Mechanics	None	Different	Yes	Iconic repr.	No
Mayer et al. (2007) expe 2	0.310	Conceptual	Remember	Mechanics	None	Different	Yes	Iconic repr.	No
Mayer et al. (2007) expe 2	0.700	Conceptual	Understand	Mechanics	None	Different	Yes	Iconic repr.	No
Mayer, Hegarty, Mayer, and Campbell (2005) expe 1	−0.199	Conceptual	Remember	Meteorology	None	Different	Yes	Iconic repr.	No
Mayer et al. (2005) expe 1	−0.521	Conceptual	Understand	Meteorology	None	Different	Yes	Iconic repr.	No
Mayer et al. (2005) expe 2	−0.364	Conceptual	Remember	Mechanics	Light	Different	Yes	Iconic repr.	No
Mayer et al. (2005) expe 2	−0.897	Conceptual	Understand	Mechanics	Light	Different	Yes	Iconic repr.	No
Mayer et al. (2005) expe 3	−0.712	Conceptual	Remember	Geology	None	Different	Yes	Iconic repr.	No
Mayer et al. (2005) expe 3	−0.561	Conceptual	Understand	Geology	None	Different	Yes	Iconic repr.	No
Mayer et al. (2005) expe 4	−0.955	Conceptual	Remember	Mechanics	None	Different	No	Iconic repr.	No
Mayer et al. (2005) expe 4	−0.402	Conceptual	Understand	Mechanics	None	Different	No	Iconic repr.	No
McCloskey and Kohl (1983) expe 2	0.062	Conceptual	Understand	Physics	Light	No textual info	Yes	Iconic repr.	Yes
Münzer, Seufert, and Brünken (2009)	0.675	Conceptual	Understand	Biology	None	Narration	Yes	n/a	No
Münzer et al. (2009)	0.308	Factual	Understand	Biology	None	Narration	Yes	n/a	No
Nerdel (2003) expe 2	0.445	Conceptual	Understand	Biology	System-paced	Written	Yes	Iconic repr.	Yes
Nerdel (2003) expe 2	0.346	Factual	Understand	Biology	System-paced	Written	Yes	Iconic repr.	Yes
Nerdel (2003) expe 3	−0.211	Conceptual	Understand	Biology	System-paced	Written	Yes	Iconic repr.	Yes
Nerdel (2003) expe 3	0.041	Factual	Understand	Biology	System-paced	Written	Yes	Iconic repr.	Yes
Nicholls and Merkel (1996) expe 1	0.417	Conceptual	Understand	Biology	Full	Different	n/a	n/a	Yes
Paik and Schraw (2013)	−0.346	Conceptual	Apply	Mechanics	None	Narration	Yes	Iconic repr.	No
Paik and Schraw (2013)	−0.036	Factual	Remember	Mechanics	None	Narration	Yes	Iconic repr.	No
Pane, Corbett, and John (1996)	0.271	Conceptual	Understand	Informatics	Full	Written	No	Iconic repr.	No
Pane et al. (1996)	−0.083	Factual	Understand	Informatics	Full	Written	No	Iconic repr.	No
Park and Gittelman (1992)	−0.498	Conceptual	Understand	Informatics	None	n/a	n/a	n/a	No
Rebetez (2004)	0.381	Conceptual	Apply	Astromony	None	Narration	No	Iconic repr.	No
Rebetez (2004*)	0.486	Conceptual	Understand	Astromony	None	Narration	No	Iconic repr.	No
Rebetez, Sangin, Bétrancourt, and Dillenbourg (2010)	0.264	Conceptual	Apply	Astromony	None	Narration	No	Iconic repr.	No
Rebetez et al. (2010)	−0.377	Conceptual	Apply	Geology	None	Narration	No	Iconic repr.	No
Rebetez et al. (2010)	0.770	Conceptual	Understand	Astromony	None	Narration	No	Iconic repr.	No
Rebetez et al. (2010)	0.093	Conceptual	Understand	Geology	None	Narration	No	Iconic repr.	No
Rieber (1989)	0.093	Conceptual	Remember	Physics	None	n/a	n/a[D]	Abstract repr.	Yes
Rieber (1989)	0.117	Conceptual	Understand	Physics	None	n/a	n/a[D]	Abstract repr.	Yes
Rieber (1989)	0.072	Factual	Remember	Physics	None	n/a	n/a[D]	Abstract repr.	Yes

(continued on next page)

(*continued*)

Study	Hedges' s g	Bloom revised taxonomy		Instructional domain	Control presence	Sensory mode of commentary	Cueing	Visual representation	Included in Höffler and Leutner (2007)
		Knowledge dimension	Cognitive dimension						
Rieber (1989)	0.086	Factual	Understand	Physics	None	n/a	n/a[D]	Abstract repr.	Yes
Rieber (1991)	0.525	Conceptual	Apply	Physics	None	Narration	Yes	Abstract repr.	Yes
Rieber (1991)	1.903	Conceptual	Understand	Physics	None	Narration	Yes	Abstract repr.	Yes
Rieber, Boyce, and Assad (1990)	0.017	Conceptual	Understand	Physics	None	Written	yes	n/a	Yes
Rigney and Lutz (1976)	0.779	Conceptual	Apply	Chemistry	None	Written	n/a	n/a	Yes
Rigney and Lutz (1976)	0.752	Conceptual	Remember	Chemistry	None	Written	n/a	n/a	Yes
Rigney and Lutz (1976)	0.536	Conceptual	Understand	Chemistry	None	Written	n/a	n/a	Yes
Rigney and Lutz (1976)	0.630	Factual	Remember	Chemistry	None	Written	n/a	n/a	Yes
Ryoo and Linn (2012)	0.548	Conceptual	Apply	Biology	None	Written	No	Iconic repr.	No
Ryoo and Linn (2012)	0.504	Conceptual	Understand	Biology	None	Written	No	Iconic repr.	No
Scheiter, Gerjets, and Catrambone (2006)	0.144	Conceptual	Apply	Mathematics	None	Written	No	Iconic repr.	No
Scheiter et al. (2006)	−0.450	Conceptual	Understand	Mathematics	None	Written	No	Iconic repr.	No
Schneider (2007) expe 1	0.641	Conceptual	Analyze	Mechanics	System-paced	Written	No	Iconic repr.	No
Schneider (2007) expe 1	−0.618	Conceptual	Understand	Mechanics	System-paced	Written	No	Iconic repr.	No
Schneider (2007) expe 1	−0.416	Factual	Remember	Mechanics	System-paced	Written	No	Iconic repr.	No
Schneider (2007) expe 1	0.576	Conceptual	Analyze	Mechanics	System-paced	Written	No	Iconic repr.	No
Schneider (2007) expe 1	−0.544	Conceptual	Understand	Mechanics	System-paced	Written	No	Iconic repr.	No
Schneider (2007) expe 1	−0.401	Factual	Remember	Mechanics	System-paced	Written	No	Iconic repr.	No
Schnotz et al. (1999) study 1	0.892	Conceptual	Apply	Geography	Full	Written	No	Abstract repr.	No
Schnotz et al. (1999) study 1	−0.423	Conceptual	Understand	Geography	Full	Written	No	Abstract repr.	No
Spotts and Dwyer (1996)	0.227	Conceptual	Understand	Biology	Light	Different	No	Iconic repr.	Yes
Spotts and Dwyer (1996)	0.457	Factual	Remember	Biology	Light	Different	No	Iconic repr.	Yes
Spotts and Dwyer (1996)	0.355	Factual	Understand	Biology	Light	Different	No	Iconic repr.	Yes
Spotts and Dwyer (1996)	0.848	Procedural	Understand	Biology	Light	Different	No	Iconic repr.	Yes
Szabo and Poohkay (1996)	0.764	Procedural	Apply	Mathematics	Light	Different	No	Iconic repr.	No
Thompson and Riding (1990)	0.381	Factual	Remember	Mathematics	None	No textual info	n/a	n/a	No
Tunuguntla et al. (2008)	0.367	Conceptual	Understand	Other	None	Narration	n/a	n/a	No
Wang et al. (2011)	−0.460	Conceptual	Analyze	Mathematics	Full	Written	No	Abstract repr.	No
Wang et al. (2011)	−0.459	Conceptual	Apply	Mathematics	Full	Written	No	Abstract repr.	No
Wang et al. (2011)	−0.233	Conceptual	Remember	Mathematics	Full	Written	No	Abstract repr.	No
Wang et al. (2011)	−0.785	Conceptual	Understand	Mathematics	Full	Written	No	Abstract repr.	No
Watson, Butterfield, Curran, and Craig (2010)	0.743	Procedural	Understand	Other	Light	Different	No	Iconic repr.	No
Wong et al. (2009) expe 1	−1.377	Procedural	Apply	Other	Light	Narration	Yes	Iconic repr.	No
Wong et al. (2009) expe 1	−0.971	Procedural	Understand	Other	Light	Narration	Yes	Iconic repr.	No
Wong et al. (2009) expe 2	0.988	Procedural	Understand	Other	None	No textual info	No	Iconic repr.	No
Wong et al. (2009) expe 3	0.932	Procedural	Understand	Other	None	No textual info	No	Iconic repr.	No
Wright, Milroy, and Lickorish (1999) expe 1	−0.152	Conceptual	Apply	Other	None	Written	n/a	n/a	Yes
Wright et al. (1999) expe 1	0.401	Conceptual	Understand	Other	None	Written	n/a	n/a	Yes
Wu and Chiang (2013)	0.597	Conceptual	Understand	Mathematics	None	No textual info	No	Iconic repr.	No
Yang, Andre, & Greenbowe (2003)	0.281	Conceptual	Apply	Chemistry	None	Different	Yes	n/a	Yes
Yang, Andre, & Greenbowe (2003)	3.591[B]	Conceptual	Understand	Chemistry	None	Different	Yes	n/a	Yes

[A] Data of experiment 2 were merge data.
[B] Outliers recoded to 2.03 for subsequent analyses.
[C] Outliers recoded to - 1.08 for subsequent analyses.
[D] Information about commentary text was originally provided, but as data were merged, this information in no more available.
n/a = no data available.

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