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Comparing apples and oranges? A critical look at research on learning from statics versus animations



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ABSTRACT

Many of the studies that have compared the instructional effectiveness of static with dynamic images have not controlled all the moderating variables involved. This problem is present not only in instructional pictures concerning the curricular topics (e.g., science, technology, engineering and mathematics: STEM), but also in those depicting extracurricular tasks (e.g., human movement tasks). When factors such as appeal, media, realism, size, and interaction are not tightly controlled between statics and animations, researchers may often be comparing apples with oranges. In this review, we provide a categorization of these confounding variables and offer some possible solutions to generate more tightly controlled studies. Future research could consider these biases and solutions, in order to design more equivalent visualizations. As a result, more conclusive evidence could be obtained identifying the boundary conditions for when static or dynamic images are more suitable for educational purposes, across both curricular and extracurricular tasks.

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1. Introduction

The instructional potential of dynamic visualizations (e.g., videos, films, and animations) has been investigated for many decades. Researchers have often been motivated to show that dynamic visualizations have clear learning advantages. Whereas it is often observed that instructional animations and videos are engaging and influential (e.g., [Umanath, Butler, & Marsh, 2012](#)), when compared to static images the supporting evidence is mixed. As noted previously by [Tversky, Morrison, and Betrancourt \(2002\)](#), statics versus animation comparisons are not always tightly controlled against moderating variables. The main aim of this review is to categorize some key moderating variables, and present them as *biases* when used unmatched in static versus animation studies. When describing each bias, we provide examples and possible solutions to control them. We also show that some studies have included these biases deliberately as part of their designs, and that many include more than one bias.

Unmatched comparisons have emerged in many instructional disciplines, most notably in educational areas where images are key assets, such as in science, technology, engineering and mathematics (STEM). There are also ill-controlled comparisons in instructional fields less related to the curriculum. From these non-formal educational areas, we focus on tasks that require

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learning a human movement skill. Although both STEM and human movement tasks show these biases, there is a fundamental difference in how they are affected by either static or animated presentations, as described next.

2. Instructional task and statics versus animations

From the research that has compared animations with statics, evidence has emerged that human movement is a key moderating variable. Humans have evolved to learn some types of movement better than others, particularly those that aided the survival of the species. As a result, such evolved movements and their corresponding actions are often easily learned by present day humans. Learning these movements and actions was described by Geary (1995) as *biologically primary abilities*. An example of biologically primary ability is to follow and mimic human movement. Modern humans can learn tasks that involve body and hand movements rather easily, because evolution has equipped us to learn these vital movements based on the vast millennia spent interacting with other humans. In contrast, non-evolved motion is much harder to learn. Non-evolved tasks, such as those not requiring human movement for example, have been termed as *biologically secondary abilities* (Geary, 1995, 2002). This distinction has links to the *dual-process theories* of psychology, which assume that there are two distinguishable systems coexisting in the brain: the first one to evolve is regarded as faster and more intuitive than the one that evolved later, which is slower and more analytical (see Barrouillet, 2011; see also Overton & Ricco, 2011).

Although learning many human movement skills can be achieved rather easily, the evidence suggests that the observed motions need to be natural rather than paused (e.g., Shimada & Oki, 2012), following our evolved primary system to cope with real-time and natural human movements (see also Kilner, Paulignan, & Blakemore, 2003; Press, Bird, Flach, & Heyes, 2005). Animations can depict many different types of movement. For example, they can show real-time human movement. Because animations can show actual motion of human parts, they have been found to be better instructional resources than static pictures to depict tasks involving fluent body and hand movement. Research on whole-body tasks (e.g., Valenti & Costall, 1997; Williams, North, & Hope, 2012) and also on manipulative-procedural tasks (e.g., Ayres, Marcus, Chan, & Qian, 2009; Castro-Alonso, Ayres, & Paas, 2015a; Michas & Berry, 2000) has supported an advantage for instructional animations over statics. Furthermore, the meta-analysis by Höffler and Leutner (2007) comparing static pictures with animations (76 pair-wise comparisons), found that the strongest effect in favor of animations was for manipulative-procedural tasks ($d = 1.06$). Nevertheless, there are still studies that cannot show advantages of animations over statics for primary human movement tasks. For example, Ganier and de Vries (2016) asked medical students to learn to perform sutures from looking at either photographs (statics) or videos (animations), and observed that the quality of the procedures performed was better when learned from the static images. Despite this unfavorable result, the overall evidence generally supports the conclusion that when learning human procedural tasks, animations have an advantage over static pictures.

The opposite pattern can be predicted for biologically secondary tasks. Because these tasks show movement and depictions in non-evolved contexts, we currently cannot deal with them as effectively as with primary tasks (Paas & Sweller, 2012; Sweller, Ayres, & Kalyuga, 2011). It has long been established that, due to the processing and storage constraints of working memory, it cannot manage many new elements simultaneously (e.g., Cowan, 2001; Miller, 1956) or for a relatively long time (e.g., Peterson & Peterson, 1959). These limitations are most noticeable in biologically secondary presentations that contain very fast or transient depictions, whose elements can disappear from the screen before learners are able to process and integrate the information. Thus, the transient information generated by some animations can produce negative instructional effects (see Ayres & Paas, 2007; see also Lowe, 1999), and a number of compensating strategies are required to manage this transiency, in order to improve the educational potential of animations (see Castro-Alonso, Ayres, & Paas, 2014a, 2015b). Consequently, because static pictures are less transient than animations, there are theoretical grounds for predicting that they might be better suited as instructional resources to depict biologically secondary tasks such as those topics usually found in the education curriculum.

Although some evidence has been found to support the advantage of static presentations for biological secondary tasks, the evidence is very mixed. For example, focusing on the STEM fields and expository (causal) visualizations, there is conflicting evidence. There are studies supporting: (a) static pictures over animation (e.g., Chanlin, 2001; Koroghlanian & Klein, 2004; Scheiter, Gerjets, & Catrambone, 2006); (b) animation over statics (e.g., Lin & Atkinson, 2011; Marbach-Ad, Rotbain, & Stavvy, 2008; Ryoo & Linn, 2012; Yarden & Yarden, 2010); and (c) neither as better than the other (e.g., Höffler & Schwartz, 2011; Kühl, Scheiter, Gerjets, & Gemballa, 2011; Lewalter, 2003). Recently, Berney and Bétrancourt (2016) conducted a meta-analysis (including many of these mentioned studies, in a total of 140 pair-wise comparisons), concerning expository visualizations mostly in STEM domains, and found an overall significant advantage (Hedge's $g = 0.23$) for animations over statics. In this update of the previous meta-analysis by Höffler and Leutner (2007), it was observed that only 31% of the studies showed animation dominance, whereas 10% of the comparisons supported statics, and 59% demonstrated no significant differences between the visualizations. Thus, even though there was an overall superiority of animations, the majority of studies (69%) did not show an animation advantage.

In summary, though evidence tends to show that animations may be better for primary tasks such as object manipulations, and under some conditions statics may be better for secondary tasks, the results are far from conclusive. To explain the inconsistencies from studies that have compared statics to animations (for both biologically primary and secondary tasks), we argue that in many cases the variables involved were not properly controlled. Critically, this methodological problem also affected the meta-analyses described above (Berney & Bétrancourt, 2016; Höffler & Leutner, 2007). In the next section, we describe several of the unmatched comparisons contained within statics and animations research.

3. Biases in the statics versus animation comparisons

Previously, [Tversky et al. \(2002\)](#) noted that many of the studies comparing static images to animations failed to control all the variables involved, such as element variety or degrees of interaction. More than a decade later, these biased comparisons persist (e.g., [Akinlofa, Holt, & Elyan, 2013](#); [Hong, Lin, Hwang, Tai, & Kuo, 2015](#)), where variables such as appealing extras, the quantity of elements included, and format size are not comparable between the visualizations, thus becoming confounding factors. We extend the earlier work of [Tversky et al. \(2002\)](#) by (a) showing that the wide-scale presence of biases still exists, (b) identifying some new biases, (c) categorizing the biases into separate sections, and (d) providing examples and guidelines to avoid each bias.

It should be noted that sometimes confounds are deliberately included by researchers to create specific learning conditions. It should also be acknowledged that there are many studies (e.g., [Catrambone & Seay, 2002](#); [Fiorella & Mayer, 2016](#); [Kim, Yoon, Whang, Tversky, & Morrison, 2007](#)) that use unbiased comparisons between static and animated instructional displays.

In order to provide guidelines to design future controlled statics vs. animation comparisons, we describe seven biases that we have identified in the literature (see [Table 1](#) and [Fig. 1](#)), and provide potential solutions. As these confounding variables are independent, they can be accumulative. Consequently, we argue that each bias should be separately controlled or avoided when pursuing comparable visualizations.

Note that each bias can lead to a positive, negative, or neutral result, implying contrasting interpretations (see [Table 2](#)). For example, as described next in the appeal bias, one study ([Wu & Chiang, 2013](#)) included appealing colors and shades only in the animation and not in the static condition. This bias toward animation lead to a positive outcome, as the animated format outperformed the static condition. Had the bias been avoided, the effect favoring animation could have been smaller. In contrast, another study ([Hong et al., 2015](#)) included the appealing element of fish only in animation, but in this case the bias toward animation lead to a negative result, as the statics format showed the higher performance. Had the bias been avoided, the effect favoring statics could have been higher.

Importantly, the following discussion provides only some key examples of biases in the literature. There are more studies showing problematic comparisons for each category, but a more comprehensive account is beyond the scope of this review.

3.1. Appeal bias

An appeal bias is observed when certain attractive features are included in one of the visualizations only, generally in the animations. Note that this bias concerns differences in *features* not in *number* of elements; the latter is considered a *variety bias* (see below). In other words, an appeal bias concerns the *quality* of the visual elements, and a variety bias concerns the *quantity* of their total.

As shown in [Table 1](#), we subdivided the appeal bias into two subcategories: *color*, and *other features*, echoing that color is the typical feature not matched in studies of instructional visualizations. An example of color bias is the quasi-experiment by [Yang, Andre, Greenbowe, and Tibell \(2003\)](#), where introductory chemistry students attended a lecture about the electrochemical processes of a flashlight. The class where the lecture's explanation was supplemented with colored animations outperformed the class given supplemental monochromatic statics. Although this bias favoring animation was recognized by the authors, it casts a doubt over the validity of the findings, as color is a feature that affects multimedia learning (e.g., [Mayer & Estrella, 2014](#)). An obvious solution to the appeal bias of color would be to compare visualizations that are matched in terms of quantity and quality of colors.

Besides a non-matched use of color, there are other appealing features that have not been controlled when comparing static and dynamic images. An example of this appeal bias can be found in the study by [Wu and Chiang \(2013\)](#) with university

Table 1
Examples of biases when comparing statics versus animations.

Type of bias	Statics	Animation	Reference
Appeal			
Color	Monochromatic	Colored	Yang et al. (2003)
Other features	Boxes	Fish	Hong et al. (2015)
Variety	Added pointers	No added pointers	Akinlofa et al. (2013)
	No hands	Hands	Türkay (2016)
Media	Paper	Computer screen	Mayer et al. (2005)
	Paper	Film projection	Laner (1955)
Realism	Abstract illustrations	Realistic film	Laner (1955)
	Computer fonts	Photos of handwriting	Luzón and Letón (2015)
Number	Many	One	Wong et al. (2009)
Size	Small	Large	Ng et al. (2013)
	Large	Small	Akinlofa et al. (2014)
Interaction			
Secondary	No pace buttons	Pace buttons	Watson et al. (2010)
	Scroll bar	No scroll bar	Marcus et al. (2013)
Primary	No draggable elements	Draggable elements	Akinlofa et al. (2013)

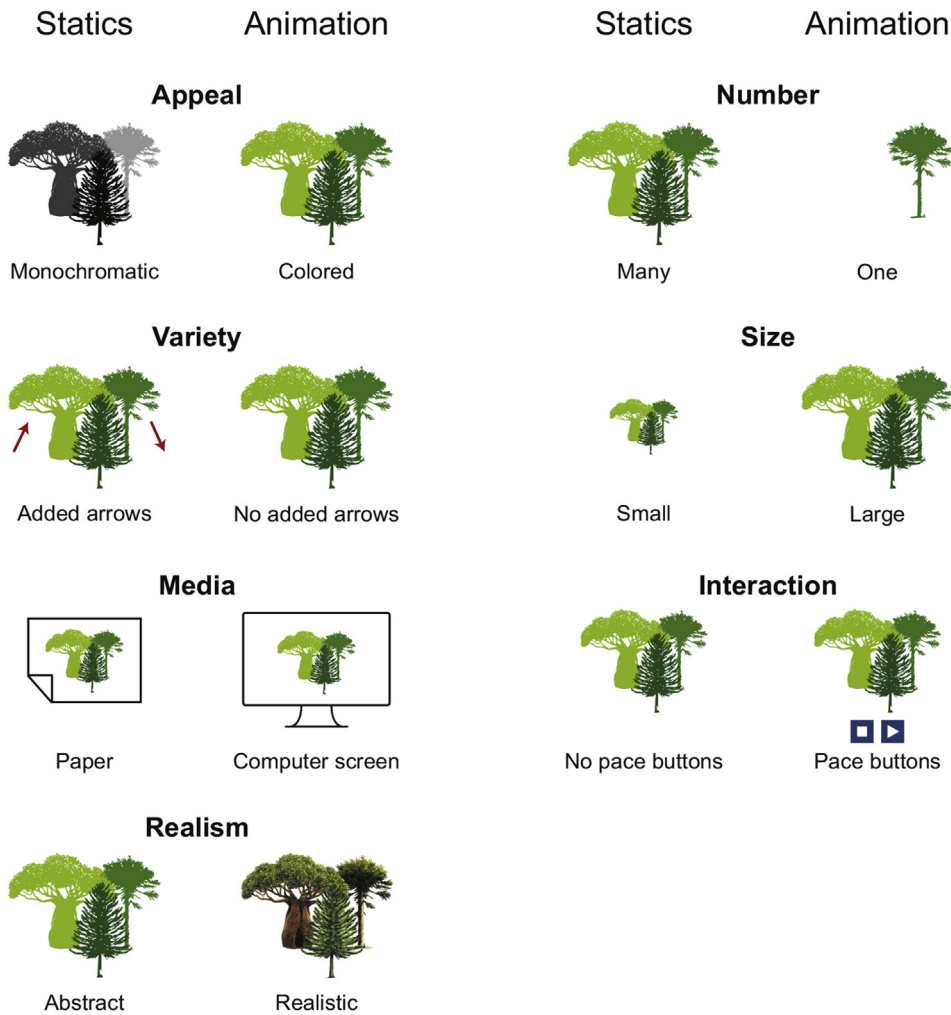


Fig. 1. Pictorial examples of biases when comparing statics versus animations.

students learning engineering orthogonal projections, where a rotating static group was compared to a rotating animation condition. Only the animated format included color and lighting in the shapes, showing appeal biases in color and in other features (shades and lights). This appeal bias toward the rotating animation might have influenced the finding that the animation showed significantly higher comprehension scores than the rotating static condition. Hong et al. (2015) investigated two groups of elementary school students learning Chinese idioms through two different computer games. One game

Table 2
Examples of biases and results favoring statics or animations.

Type of bias	Bias toward	Results favoring	Reference
Appeal	Animation	Animation	Wu and Chiang (2013)
	Animation	Statics	Hong et al. (2015)
Variety	Statics	Animation	Akinlofa et al. (2013)
	Animation	Animation	Türkyay (2016)
Media	Undetermined	Statics	Mayer et al. (2005)
	Undetermined	Animation	Marbach-Ad et al. (2008)
Realism	Animation	Animation	Luzón and Letón (2015)
Number	Statics	Statics	Ganier and de Vries (2016)
	Statics	Animation	Wong et al. (2009)
Size	Statics	Animation	Akinlofa et al. (2014)
	Animation	Animation	Ng et al. (2013)
Interaction	Statics	Animation	Marcus et al. (2013)
	Animation	Animation	Chien and Chang (2012)

included static elements (boxes), while the other had animation elements (swimming fish). The better performance was observed in the group playing the static game. However, the animated game presented the appealing element of fish, which was replaced by boxes in the static format. Fish may have appealing features (life, eyes, shapes, etc.), which boxes do not have. However, in this case, the appeal bias toward animation was potentially counterproductive.

Because appealing features can have positive or negative effects on learning with visualizations (e.g., Mayer & Estrella, 2014; Sánchez & Wiley, 2006), the bias of appealing features should be avoided in statics vs. animation comparisons. One method to overcome this bias is to match the visual characteristics shown in the compared visualizations.

3.2. Variety bias

Tversky et al. (2002) noted that there were biased comparisons between static and animated visualizations in terms of their quantity of information. We refer to this problem as a variety bias, which occurs when one of the instructional formats presents more elements than the other, thus showing a greater visual variety. In multimedia learning, this extra quantity of elements could result in an advantage (*signaling principle*, see van Gog, 2014) or a disadvantage (*redundancy principle*, see Kalyuga & Sweller, 2014), in addition to possible static versus animation differences.

One typical example of this bias is when static pictures show movements with arrows and other signaling devices, but these elements are not presented in the animated format. Lewalter (2003) investigated the learning of optical phenomena by education and psychology undergraduates shown on-screen texts through either statics or animations. The researcher did not find significant differences between the visualizations, despite that static pictures showed elements (lines and arrows) conveying the relevant motion of the STEM topic, which were absent in the animation. The study by Rieber (1990) with elementary school children learning Newton's laws of motion, revealed that animation was a better instructional tool than static pictures. However, the study showed a bias toward static images, as only the statics included arrows and path lines to display motion trajectories. Similarly, Akinlofa et al. (2013) investigated aircraft maintenance engineers learning to disassemble a Lego™ truck model, where only the statics condition contained visual cues (e.g., pointers) to identify important components of the model. The other two experimental groups, animation (video) and interactive virtual space, did not include any signal. Nevertheless, in spite of this variety bias toward static pictures, both video and interactive space presentations led to faster and more accurate solutions than the statics group on this human movement task.

In contrast, an example of variety bias toward the animated format is the study by Türkay (2016) with adult participants learning advanced physics. The two visualization formats of the study were not equivalent, as the whiteboard animation showed hands drawing the elements, but the hands were not included in the static sequential condition. Although both formats produced comparable learning outcomes, the animations were rated as more enjoyable. The presence of signaling hands only in the dynamic pictures could have biased the results.

There are some STEM instructional contents where the variety bias seems unavoidable to make the visualizations meaningful. For example, when motion or force has to be shown as static images, the only option might be to include arrows or similar signals in the stationary images. However, to avoid the variety bias in this case, the same arrows or signals could be also added in the animated format, in order to match the variety shown in the statics.

3.3. Media bias

A media bias can be detected when contrasting visualizations are shown in different media. As every medium has unique instructional features, variations in the media can generate different learning outcomes (e.g., Daniel & Woody, 2013). The potential for a mismatch is great as instructional media can include a diverse range of formats such as television, film, mobile phones, virtual reality, books, transparencies, and so forth. The most common media bias is, arguably, the comparison between paper-based statics and screen-based computer animations. In this case, a sheet of paper has unique properties (e.g., flexible, portable, translucent, gyratory, etc.) that could be used for the learners' needs. Analogously, a computer screen is unique in some capabilities (e.g., change of contrast and brightness) that are lacking in the paper format.

An example of that usual media bias is the study by Mayer, Hegarty, Mayer, and Campbell (2005). The authors conducted four experiments with psychology college students given different STEM topics to learn (lightning, toilet tank mechanics, ocean waves, and car brakes). They observed two out of four effects on retention tests (ocean waves and car brakes) and two out of four effects on transfer tests (lightning and toilet tank), always favoring statics over animations. All four experiments compared paper statics to computer screen animations, so it is difficult to conclude whether the medium (paper vs. computer) or the presentation format (statics vs. animation) caused the difference. Likewise, Marbach-Ad et al. (2008) investigated high-school participants studying molecular genetics with instruction supplemented by either illustration or animation activities. Again, the static picture group was provided the depictions via textbook and paper media, and the dynamic image students were given the supplements through computers. Marbach-Ad et al. observed that animations were more effective than statics. Similarly, Laner (1955) compared university students learning about a machine gun's trigger mechanism with either static or animation presentations. The author reported no significant differences between the group shown a film and the group given paper static diagrams.

Following the argument made by Clark and Feldon (2014), we do not advocate for one instructional medium over another, hence it is undetermined (see Table 2) whether these media biases are tilted toward statics or animation. Nevertheless, we do warn against comparisons employing different media, as different devices offer different learning opportunities. The most

straightforward guideline to avoid the media bias is to design the visualizations for the same medium. In consequence, comparisons would be better made on-screen, where both statics and animations can be produced.

3.4. Realism bias

A realism bias is observed when an abstract animation is compared to a realistic (photographic) static, or vice versa (cf. Hegarty, 2004). The study of Laner (1955) just described, in addition to a media bias also presented a realism bias, as a realistic film was compared to abstract illustrated statics.

Besides comparing opposite examples of realism, there are also intermediate categories. For example, Höffler (2010) considered four different categories to classify both static and animated images progressing toward realism as: (a) schematic, containing purely symbolic and abstract illustrations; (b) rather simple, with few details; (c) rather realistic, with many details (e.g., mostly correct in scale and color); and (d) photo-realistic, meaning photos or videos. Any comparisons between static and animated depictions that are not in the same category will fall into a realism bias. For example, a study by Luzón and Letón (2015), in which secondary education students learned a basic probability task, used photo-realistic texts only in the animated format. In fact, the animations included photographs of handwritten equations, whereas the static version showed computerized fonts. The higher realism of animations may have contributed to their advantage over the statics, as revealed in both retention and transfer tests.

Visual realism can affect learning from visualizations (cf. *visual complexity* in Machado et al., 2015). For example, research on STEM multimedia learning suggests that different degrees of realism may serve different instructional purposes (e.g., see Treagust & Tsui, 2013) or affect learners differently according to their individual characteristics (e.g., Brucker, Scheiter, & Gerjets, 2014). As such, comparisons between static and animated visualizations should be matched on the level of realism. In other words, a possible solution for the realism bias would be to conduct the comparisons within the same realism category such as those described in Höffler (2010).

3.5. Number bias

A number bias is generated when one of the formats is presented in more images than the other. This is typical when many simultaneous static images are compared to a single animation. For example, when Ryoo and Linn (2012) compared two groups of seventh graders learning the STEM topic of energy in photosynthesis, they observed a better performance on those watching the animated version. However, the authors compared 15 simultaneous static images to a single animation, thus showing a bias toward statics. Also, in an investigation with university students learning how chemical surfactants are involved in washing clothes, Höffler and Schwartz (2011) reported no noticeable differences between the visualizations, after comparing one animation to four simultaneous static pictures. In an experiment with undergraduate education students memorizing the position of abstract symbols on a grid, Castro-Alonso, Ayres, and Paas (2014b) reported better outcomes for the static version. However, the comparison was between one animation and eight simultaneous static displays. Similarly, when showing medicine students a multi-step task of performing sutures, Ganier and de Vries (2016) observed that a total of 52 static images tended to be better than a sum of 10 videos. In an experiment with primary school children learning origami tasks, where Wong et al. (2009) observed better outcomes for the dynamic group, the comparison was made between 42 simultaneous static frames and one animation. As a final example, with a Lego manipulative task for university students, Castro-Alonso et al. (2015a) compared one animation with six or 15 simultaneous static pictures. In this case, the authors purposely investigated a number bias and observed that animation outperformed 15-statics but not 6-statics, thus giving indirect evidence that 6-statics was better than 15-statics.

Although the evidence is mixed supporting either the presentation of few (e.g., Castro-Alonso et al., 2015a) or many (e.g., Ganier & de Vries, 2016) images as the best instructional method, the number bias should be avoided. Nevertheless, sometimes the bias seems inevitable to design an intelligible visualization. For example, when there is a need to show all the key steps of a task, many static images have to be produced, each showing one of the steps. In that case, one solution to avoid this bias would be to show the same number of animated depictions, instead of one single animation. Alternatively, the many steps could be designed inside one comprehensive static image, instead of many separate statics. (There are other methods to create effective learning environments, such as showing together key static frames and a single animation (e.g., Arguel & Jamet, 2009), but these are not direct solutions to biased comparisons between statics and animation). Commonly, when controlling the number bias, it is also important to consider a related problem, the size bias, which is described next.

3.6. Size bias

A size bias is observed when one of the depictions is noticeably larger than the other. This can cause the larger visualization to be easier to study than the smaller one, as evidence can be found showing that size variations leads to differences in perceptibility of the elements presented (Schnotz & Lowe, 2008). When using simultaneous static displays, the size bias usually coincides with the number bias, because having many static images shown simultaneously demands smaller images to fit the display. For example, Ng, Kalyuga, and Sweller (2013) investigated technical education students learning about an electrical circuit. The authors compared groups of participants given different instructional presentations. Because the static formats were composed of six simultaneous depictions, their individual size was at least half that of the animated formats.

The study revealed better learning outcomes for the animated groups, but the larger animated sizes may have biased the results. Similarly, in a study with university participants studying fish motion patterns, [Imhof, Scheiter, and Gerjets \(2011\)](#) compared an animated condition to a simultaneous static format in which every static image was half the size of the animation. In spite of this size bias of larger dynamic pictures, there were no significant differences in learning between both groups.

In contrast, there are cases where animation is the reduced format, hence showing a bias favoring statics. In a study with university participants navigating in virtual mazes, [Akinlofa, Holt, and Elyan \(2014\)](#) observed that the group given animated map aids outperformed those given static aids, even though the animated depictions were substantially smaller. In this case, the size bias could have favored the static format, but it did not. Notably, the study by Akinlofa and colleagues shows that the reduced format does not need to be presented as many images, indicating that size and number bias are independent problems. A straightforward method to solve the size bias is to design all visualizations with the same dimensions.

3.7. Interaction bias

An interaction bias is produced when the images are not matched in their features of interactivity. Here, we specifically focus on the interaction *learner–content* used in web-based instruction (e.g., [Chou, 2003](#)). As observed by [Tversky et al. \(2002\)](#), generally animations give more interaction to learners than static pictures. Following the differentiation noted by [Plass, Homer, and Hayward \(2009\)](#), we categorize two types of interaction: (a) *secondary interaction* (e.g., clicking navigational or pace-control buttons) is our definition of affordances that do not change the learning content; and (b) *primary interaction* (e.g., dragging and changing the depicted elements), includes the interactivity that affects the learning content.

Regarding secondary interaction bias, an example where only the animation was provided with pace-control buttons is the study by [Watson, Butterfield, Curran, and Craig \(2010\)](#) with adult participants learning to assemble an engineering model device. Although the authors did not observe significant differences between the visualizations, statics presented no interaction, but animations included interactive buttons to rewind, fast forward, and pause the depiction. Similarly, in the study by [Akinlofa et al. \(2014\)](#) described in the previous section, the bias tilted toward animation, as only the animated visualization presented buttons to control its pace. Examples of the statics formats provided with more secondary interactivity are the studies by [Ayres et al. \(2009\)](#) and by [Marcus, Cleary, Wong, and Ayres \(2013\)](#), in which participants learned the human movement task of tying knots. In these experiments, only the static pictures group had a scroll bar in their visualization. This interaction feature could have been counterproductive, as the animated video groups performed better in both studies.

As mentioned, primary interactivity features can also show biases. For example, [Chien and Chang \(2012\)](#) investigated tenth grade high school females learning to use a topographic instrument by watching visualizations with different degrees of interactivity. The comparison between statics and animation, both presenting a secondary interactive format (i.e., pause and play buttons), showed no significant differences. However, a full interactive animation, which also included the primary interactions of dragging and controlling the topographic instrument, was the most effective. Similarly, in the study with engineers given a Lego truck to disassembly, [Akinlofa et al. \(2013, see Section 3.2\)](#), observed that the most effective learning condition was the interactive virtual space, where participants could drag the computer replicas of the Lego pieces. This primary interactive display was a better instructional format than two simpler secondary interactive visualizations (static pictures and video), where the users could only change the presentations' pace.

Because interactive features can help understanding STEM concepts (e.g., [Wang, Vaughn, & Liu, 2011](#); but see [Pedra, Mayer, & Albertin, 2015](#)), they must be controlled in unbiased static versus animation comparisons. However, sometimes statics cannot include as many interactive facilities as animations (see [Tversky et al., 2002](#)), which may limit the scope of research that can be conducted linking interaction with presentation types. Hence, if more sophisticated types of interaction are the main research focus, then it may be prudent not to compare statics with animations at the same time. In contrast, if comparisons between statics and animations are the main focus, then the interaction bias should be avoided. Solutions to avoid this bias are either to match all features of interactivity in the compared presentations (both secondary pace buttons and more advanced primary interaction tools) or to avoid including interactive facilities in the visualizations.

4. Discussion

Despite a long research tradition investigating the educational effectiveness of both static and dynamic pictures, their relative instructional importance may be difficult to assess. One key factor to consider when comparing both visualizations is the instructional task at stake: our evolved mind seems to be more suited to learn animated primary tasks and static secondary tasks. However, clear conclusions are not easy to draw, yet, as many of the studies comparing static and animated formats (for both primary and secondary tasks) have presented uncontrolled biases. We discussed appeal, variety, media, realism, number, size, and interaction biases as example of seven confounding variables.

Over a decade ago, [Tversky et al. \(2002\)](#) observed that biases in comparisons between static and dynamic images existed. Our review indicates that researchers are still designing experiments that contain them, and thus to some extent ignoring the messages inherent in the review by Tversky and colleagues. For example, we reported two meta-analyses ([Berney & Bétrancourt, 2016](#); [Höffler & Leutner, 2007](#)) that included several of the studies included here (e.g., [Lewalter, 2003](#); [Mayer et al., 2005](#); [Ryoo & Linn, 2012](#); [Wu & Chiang, 2013](#); [Yang et al., 2003](#)) that did not control these bias factors, which suggests some loss of validity. Clearly much greater attention to biases is needed into future meta-analyses as well as individual

studies to take the field forward. We believe that the present review, categorizing and giving examples of these problematic current comparisons, was necessary to re-emphasize the original message of Tversky et al. (2002). In addition, we adopted a practical approach by providing guidelines for avoiding and controlling these problems in future investigations.

Notably, as we have acknowledged, there are studies successfully avoiding these biases, and there are experiments that intentionally made problematic comparisons for research purposes. In addition, sometimes the learning task might be more achievable when presented in a static display that is not matched completely to the animated format, or vice versa. To mention one example of the number bias, when a task involves procedural steps, showing many static images may be the unavoidable method to show equivalent information to a single dynamic presentation of all the steps. In this case, purposely making a number bias of more static than animated images seems to be more appropriate for the learner.

As stated previously, our aim was not to complete a total review of the literature as such, but to examine a number of key studies that enable us to draw some concrete conclusions. A much larger study completed in the future could add more information such as the frequency of occurrence of each type of bias and its importance. Nevertheless, the present review clearly shows the significance of several factors on learning, and how failing to control them may produce unintended instructional consequences. The research evidence shows that all the factors documented here, namely color or other appealing visuals (e.g., Mayer & Estrella, 2014), variety (e.g., van Gog, 2014), media device (e.g., Daniel & Woody, 2013), degree of visual realism (e.g., Brucker et al., 2014), number of images shown (e.g., Castro-Alonso et al., 2015a), format size (e.g., Schnotz & Lowe, 2008), and level of interaction (e.g., Wang et al., 2011) can impact significantly on learning from visualizations. As such, biased comparisons that do not control these factors may lead to incorrect educational interpretations.

To conclude, we believe that it is necessary to consider these and possibly other biases when designing future static versus animation studies, in order to stop comparing apples and oranges. Cherry picking these biases and controlling them should be fruitful to produce more conclusive evidence toward either the static or the animated format as the more recommended instructional tool.

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