FOLIO 18/2

Research-informed Pedagogical Considerations for the Design and Use of Animation as a Teaching Tool

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Introduction

Animation can be defined as 'a simulated motion picture depicting movement of drawn (or simulated) objects' (Mayer & Moreno, 2002, p. 88). Although most people would primarily associate animation with entertainment, animated representations are frequently used as educational tools and are currently a prominent feature of multimedia learning environments. In contexts where animation is used for teaching and/or learning purposes, it is referred to as instructional or educational animation. The first applications of animation for educational purposes were animated graphics used in science to illustrate processes which are difficult to visualize, such as molecular bonding, heat transfer and storm formation. Having the capacity to show a more realistic portrayal of these phenomena through movement, animated graphics were keenly adopted as a supposedly superior alternative to the static images and texts previously used to teach these concepts (Schnotz & Rasch, 2008). Animations were also perceived as a successful way of incorporating technology in teaching and learning, thus enhancing traditional teaching methods and making them more relevant for the first generations of digital natives.

The use of animation in educational contexts has been further encouraged by the arrival of animation-design tools which, by not requiring high technical training, have made it possible for teachers and educators to create their own animations. Before this development, this type of learning material was created almost exclusively by people who had the technical knowledge to design it but who were not necessarily trained to predict its effects on learning (Kirby, 2008). User-friendly software such as PowToon and Vyond has made animation design accessible and nowadays animated videos are used in virtually every academic subject and in all educational levels ranging from primary to postgraduate education.

The popularity of educational animation has been based to a large extent on the assumption that 'animation is more interesting, aesthetically appealing, and therefore more motivating' (Kim, Yoon, Whang, Tversky & Morrison, 2007, p. 261) than other instructional tools. This belief among many educators and teachers has hindered an honest review of the role of animation in the learning process. Despite very influential research concluding that animation is not 'a magical panacea that automatically creates understanding' (Mayer & Moreno, 2002, p. 97), many practitioners still believe that generating motivation and interest might be enough to achieve learning objectives. Given the frequency and extent to which animation is being used as a teaching tool, this seems to be a timely moment to reflect on how we are designing and implementing it. The purpose of this article is to revisit the research on the effects of animation in learning, to discuss its pedagogical implications and to provide teachers and material designers with a series of practical guidelines for the design and use of educational animation.

Cognitive psychology research

John A. Kirby points out that it is not uncommon for educational innovations to be assessed long after they are implemented (Kirby, 2008); that was precisely the case with animation, which had already been in use for more than two decades when its effects on learning started to be assessed in the early 1990s. To begin with, researchers tried to determine the effectiveness of animation in comparison to text or static graphics. The results were inconclusive and at times contradictory: in some cases animation seemed to be superior to text or static graphics, in other cases it did not prove to make any difference and in a few cases animation seemed to be detrimental to learning. These diverse results lead researchers to conclude that 'animation may or may not promote learning, depending on how it is used' and that research should focus on 'how animation can be used in ways that are consistent with how people learn' (Mayer & Moreno, 2002, p. 88). Nowadays the consensus among researchers is that animation has great potential as a teaching tool if it is designed and used with a series of features and conditions which have been proved to facilitate learning (Lowe & Boucheix, 2017).

Cognitive psychologists have analysed the human learning process in general and the learning process with animation in particular. Furthermore, they have been able to provide clear recommendations regarding the design of educational animation in order to ensure that learning is enhanced as much as possible (Hegarty & Kriz, 2008). The 'Cognitive Load Theory' developed by John Sweller in the late 1980s laid the basis for the most specific research on animation developed later. Sweller identified three types of memory at play in the learning process: the sensory memory, which through a verbal/auditory channel and a visual/pictorial channel collects information from the environment; the working memory, which is used to think and process information and has a limited capacity; and the long-term memory, which is the final destination of what we learn and has unlimited capacity (Brame, 2015).

The limited capacity of the working memory has important implications for the design of educational material. When materials are poorly designed (e.g. unclear instructions, too much extra information, level of difficulty inappropriate to the learner's previous knowledge, confusing layout), they will use too much working memory, not leaving enough to do the necessary processing of information to achieve the learning objective. Any cognitive effort which is imposed by a poor design of the instructional material and is not directly related to the achievement of the learning objective is defined by Sweller as 'extraneous cognitive load' (Sweller, 1994, p.302). Thus, Cognitive Load Theory points at the importance of designing learning materials which involve as little extraneous cognitive load as possible so that working memory has enough capacity left to carry out the necessary processing leading to understanding.

Cognitive Load Theory had implications for the design of educational learning materials in general. Mayer and Moreno built on these ideas to explain how people learn in multimedia contexts specifically. They developed the 'Cognitive Theory of Multimedia Learning', which maintains that humans have two separate channels to process visual/pictorial information and auditory/verbal information respectively, that the amount of information we are able to process in each of these channels is limited, and that deep learning only takes place when we engage in processes such as selecting the relevant information, organising it in a general cognitive structure and relating it to existing knowledge (2002). Mayer and Moreno maintain that animation can be an efficient instructional medium if it is designed in consistency with multimedia learning, which they define as 'learning from words and pictures [...] the words can be printed (e.g., on-screen text) or spoken (e.g., narration) [...] the pictures can be static (e.g., illustrations, graphs, charts, photos, or maps) or dynamic (e.g., animation, video, or interactive illustrations)' (2003, p. 43).

Research-based animation design

Like Sweller, Mayer and Moreno emphasize the importance of designing material which causes as little extraneous cognitive load as possible, so that learners are left with enough capacity to 'engage in deep processing of the essential material in the lesson' (Mayer, 2008, p. 38). The first and most obvious recommendation for animation design is therefore 'weeding', which involves eliminating all elements which do not contribute to reaching learning goals or do not facilitate understanding. Examples of extraneous cognitive load caused by animation can be images not related to the theme of the lesson, distracting movement or complex backgrounds. A very strict approach to weeding would suggest eliminating even background music, whereas more lenient versions would only recommend reducing the amount of extra information provided about the topic. How much extra information to remove when designing an animation should be based on the learners' prior knowledge of the subject, since extra information which could make understanding overwhelming for a novice could actually be helpful and motivating for a more advanced learner (Brame, 2015).

Another way of reducing extraneous load is 'signalling' (also known as 'cueing'), which involves highlighting the most relevant pieces of information so that the learners know where to focus their attention. This guides learners and reduces the cognitive effort required to select the relevant elements (Amedieu, Mariné & Laimay, 2010). When used in combination with weeding, signalling can ensure that even if some non-essential elements have been left in the animation, the learners' attention can be directed to the most relevant aspects of the material. Signalling or cueing can be done by using arrows or other graphics to point at specific parts (as shown in Figure 1), choosing different text, size or colour to make some elements more prominent, zooming or highlighting. Signalling will be particularly relevant in the case of novice learners, who will have more difficulties to identify the most relevant content of the animation.

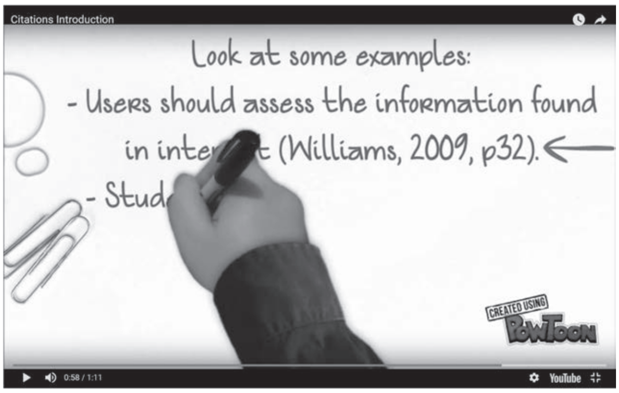

Figure 1. Animation where an arrow is used for signalling the most relevant part of the content (the citation).

A third design feature which can reduce extraneous load is to avoid using both narration and on-screen text. This is called the 'Redundancy Principle' and it is based on test results which showed that learners performed better 'after viewing a narrated animation rather than a narrated animation with concurrent on-screen text' (Mayer, 2008, p. 39). The reason why some animation designers opt for including both narration and on-text screen is their desire to accommodate both auditory and visual learners. If both narration and text are present in the animation, each learner would be able to choose whatever input they prefer depending on their learning styles. However, Mayer explains that this option can be problematic because whereas a narrated animation would have one element (i.e. images) processed through the visual/pictorial channel and another element (i.e. narration) processed through the auditory/verbal channel, a narrated animation with text would present two elements (i.e. images and text) which would have to be simultaneously processed through the visual/pictorial channel, potentially causing extraneous cognitive load in that channel and therefore hindering learning (2008). Furthermore, different studies have shown that when animation is accompanied only by narration, learners engage and remember more and their ability to transfer information increases (Brame, 2015).

It is important to clarify that the on-screen text discouraged by the Redundancy Principle would be a text reproducing what the narration is saying, which means that the animation would present identical printed and spoken words, hence making the printed words 'redundant'. The principle would not apply, however, to text consisting of key words that have the purpose of highlighting the most relevant parts for the content (Mayer & Johnson, 2008), which could also be taken as an example of signalling.

A further recommendation to reduce cognitive overload has been made in relation to the use of key words and highlighting text: to place text right next to the part of the animation it refers to. This has been called the 'Spatial Contiguity Principle', which maintains that 'people learn better when corresponding elements of the narration and on-screen text are presented near rather than far from each other on the screen' (Mayer, 2008, p. 40). When images and corresponding/explanatory text are placed apart from each other, learners are forced to scan the screen and find the connection between images and words, which adds a cognitive effort which can be avoided by placing the text closer to the image. This is particularly relevant if the learner is not given the possibility of pausing or replaying the animation and must make connections between text and image in a matter of seconds.

Figure 2. Animation where the text used to guide learners' attention to specific parts of the content (author's surname, etc.) is placed next to the elements it refers to.

Together with the recommendations mentioned above to reduce extraneous cognitive load in animation, cognitive research has also resulted in a series of principles directed at facilitating the processing of information. According to the Cognitive Theory of Multimedia Learning, the last step in the learning process would be 'generative processing' (Mayer, 2008, p. 43), which involves selecting and organising the relevant parts of the material and relating them to prior knowledge. This cognitive process is more likely to be achieved when on the one hand, the animation design helps manage the difficulty or complexity of the subject matter and on the other, it fosters engagement and deep understanding.

When the material to be learned is intrinsically complex and the processing needed to understand it is superior to the learners' cognitive capacity we talk about 'essential processing overload'. There are several animation design features that can help manage essential overload and therefore facilitate the selecting and organising of relevant information. One of these features is signalling or cueing, which has been previously mentioned as beneficial to reduce extraneous overload but which can also be useful to avoid essential processing overload, since it can make the organisation of the material and the relationship between its different parts clearer to the learner. An example of such cues could be an animation where the accompanying narration emphasizes the main ideas through intonation and signposting words such as 'first', 'second', 'as a consequence', etc. The role of these discourse markers would be to guide the attention of the learner to the most relevant parts of the animation, which has been proved to have positive effects on how much learners remember and on how difficult they perceive the subject matter to be (Jamet, Gavota & Quaireau, 2008).

'Segmenting' the animation into small units is another of the features which has proved to be efficient to reduce essential processing overload. When used in combination with signalling and weeding, segmenting can help learners organise content and integrate it with previous knowledge (Ibrahim, Antoneko, Greenwood & Wheeler, 2012). Segmenting can be done by introducing pauses after each main part of the animation, an option which can be optimized if the pause can be controlled by the learner. Another way of segmenting is to include tasks at different points of the animation and require students to complete them before they are allowed to continue (see Figures 3 and 4). Learners could be assessed on what the animation has shown previously and/or be asked to make predictions about what is going to be explained later.

Figure 3. Animation with integrated tasks. The numbers on the time line at the bottom of the screen indicate where tasks will have to be completed.

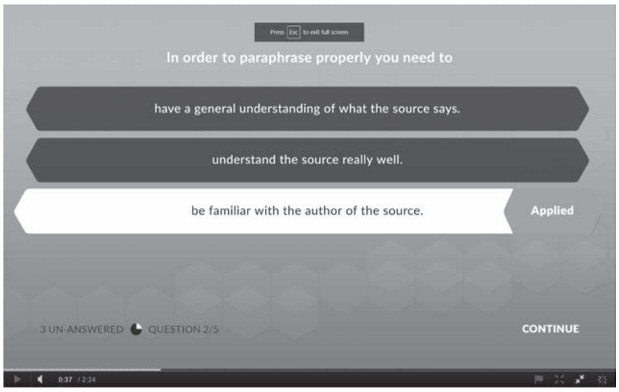

Figure 4. Quiz integrated within the animation shown in Figure 3. Learners are asked to complete the task before continuing watching the animation. The correct answers are provided at the end.

Giving learners the possibility of pausing the animation whenever they want or testing their understanding at different points of the animation are regarded as interactive features. Bétrancourt talks about the 'interactivity principle', which she defines as 'the capability for learners to interact with the instructional material' (2005, p. 287). When users have the choice of pausing the animation, rewinding and moving forward they are in control of how much content is presented to them at one time and how much they want to watch again; they are also in control of how much time to spend in each of the sections, which facilitates a progressive processing of the information. It seems that being able to interact and control the animation can enhance students' motivation and enjoyment and has been linked to better performance (Kim *et al.*, 2007; Mayer & Chandler, 2001).

Segmenting may not be necessary if a lesson is broken into a series of short animations instead of the whole content being presented in a long one. A large study about the relationship between online educational videos and student engagement revealed that the length of the videos is the factor that influences engagement the most. Results showed that the shortest videos, no longer than three minutes, had the highest engagement and that students often watched less than halfway if the videos were longer than nine minutes (Guo, Kim & Robin, 2014). Some animated video software such as PowToon recommend 60-90 seconds as the most appropriate length for animations. It has also been observed that students are more likely to engage in assessment activities after watching short videos than after watching long ones. Furthermore, video producers have pointed at the possibility of shorter videos having higher quality content, 'since it takes meticulous planning to explain a concept succinctly', which means that shorter videos could be more engaging 'not only due to length but also because they are better planned' (Guo *et al.*, 2014).

Besides the design features which can contribute to manage the intrinsic difficulty of the material, generative processing can also be fostered by building a 'sense of social partnership' between the learner and the animation (Mayer, 2008). One of the design-related principles proposed to achieve this fostering is the 'personalization principle', which maintains that people learn better if the narration in the animation has an informal or conversational style rather than a formal one, for example by using 'you' to make the message more personal or by avoiding formal structures such as passive phrases. The feeling of social partnership is also more easily achieved if the narrator's voice used in the animation is a human voice rather than a machine simulated voice (the 'voice principle'). It seems that when the narrator's voice comes from a human, 'learners might be more likely to accept the lesson as a social conversation' (Mayer, 2008, p. 44). Experimental tests carried out by Mayer and his colleagues showed that students scored higher after being instructed with animations where a conversational style (rather than formal style) and a human voice (rather than machine simulated voice) were used (Mayer, 2008). It has been suggested that informal style and human voices make learners feel that the narrator is conversing with them, which increases their engagement and effort to understand the message they are being conveyed.

The concept of social partnership is especially relevant when discussing the use of 'animated pedagogical agents' (APAs), computerized characters with human-like gestures, speech, etc. which fulfil the role of tutor or learning companion. APAs seem to contribute to learners perceiving the animation as a social exchange, therefore creating a closer connection (partnership) between them and the learning material. Some of the features of APAs that learners value the most are the verbal and non-verbal signals which resemble the ones we use in face-to-face conversation, such as gestures, facial expressions and intonation. The possibility of showing emotion on the part of APAs has proved to enhance students' learning experience in several ways. For example, an APA that seems to care about a student's progress may encourage the student to care more about his/her own progress and an enthusiastic APA may foster similar enthusiasm in the learner. It has been pointed out that 'by creating the illusion of life, dynamically animated agents have the potential to significantly increase the time that people seek to spend with educational software' (Johnson, Rickel & Lester, 2000, p. 60).

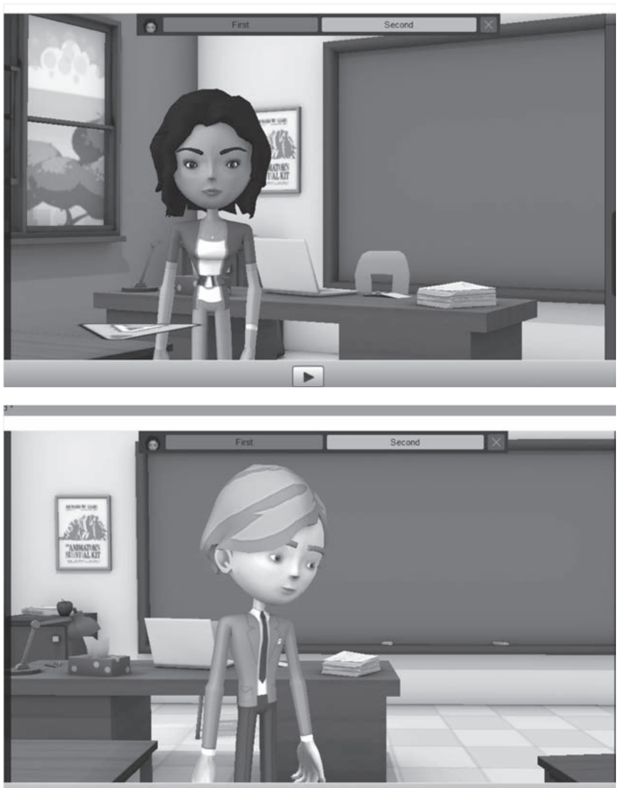

Figure 5. Two of the APAs available in the animation design software Nawmal.

Although the design features mentioned above can make a significant contribution to exploiting animation's potential as a teaching tool, they might not be sufficient. How the animations are used is equally relevant. A study carried out by Hwang, Tam, Lam & Lam (2012), where they tested animations designed following Mayer and Moreno's principles, revealed that learners had most frequently viewed the animations after reading their notes first and they suggested the addition of exercises related to the content of the animations. These reflections from students seem to indicate that the most efficient way of using animations is in combination with other teaching materials. Hegarty and Kriz also point out that in order to be efficient as a teaching tool animation must not only be designed in accordance with research-informed principles, but must also be used as just one component of a larger learning context (2008). Learning platforms such as Moodle make it possible to integrate animation with other teaching resources in a very effective way. Animations can for example be inserted in texts or be used in combination with a variety of quizzes. The combination of animation with other types of learning resources offers a varied learning experience and caters for diverse learning styles.

Conclusion

All the design-related recommendations mentioned above, regardless of whether they are meant to reduce the extraneous cognitive load or enhance generative processing, share the objective of creating animation which enhances active learning. Although it is true that achieving active learning is the purpose of *all* learning materials, not only those presented through animation, consulting research findings seems especially relevant when designing multimedia learning material. One of the main challenges of teaching with animation is avoiding overestimating the power of the attractiveness of this medium and to remember that 'learners can passively watch animations just as they can passively listen to lectures, read text, and look at diagrams' (Golding, 2008, p. 362).

Tversky's two aphorisms for animations: 'seeing isn't perceiving, perceiving isn't understanding' (Tversky, Heiser, Mackenzie, Lozano & Morrison, 2008, p. 266) clearly warn against over-relying on the supposedly intrinsic motivating factor of multimedia tools. With the technological means to create animation that we now have available and the research done so far, designers and teachers can ensure that animation is designed and used in such a way that contributes positively to learning. Future research will shed light on issues that need exploring, such as the effectiveness of specific types of cues and the role of pedagogical agents, and will surely result in new pedagogical guidelines that will allow us to exploit the educational potential of animation even further.

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Vyond, available at *https://vyond.com*

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