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Decorative animations impair recall and are a source of extraneous cognitive load

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Pink A, Newton PM. Decorative animations impair recall and are a source of extraneous cognitive load. *Adv Physiol Educ* 44: 376–382, 2020; doi:10.1152/advan.00102.2019.—Working memory is critical for learning but has a limited capacity for processing new information in real time. Cognitive load theory is an evidence-based approach to education that seeks to minimize the extraneous (unnecessary) load on working memory to avoid overloading it. The "seductive details effect" postulates that extraneous load can come from instructional design materials that attract interest but are unrelated to, and impair, learning. Presentation packages, such as Microsoft PowerPoint, have built-in decorative animated "GIFs" that are designed to make presentations more visually appealing. The aim of the study was to investigate the effect of such "decorative" animations on learning and working memory performance. We found that students were less able to recall content presented in the presence of a decorative but relevant animation compared with a still image. This effect was found with two different topics (human physiology and enzyme kinetics). Compared with still images, students also found it harder to remember animations themselves, and the self-reported mental workload required to remember them was higher. These results show that decorative animations are seductive details and are thus a source of extraneous cognitive load.

cognitive load theory; extraneous load; learning; seductive details; working memory

INTRODUCTION

A three-stage model of human learning and memory, first described by Atkinson and Shiffrin (1) in 1968, proposes that information to be learned has to pass through three forms of memory: sensory memory (or sensory processing), working memory, and then long-term memory, where learned material is stored and from which it can be recalled. New information is added to existing "schema," which are simply defined as preexisting networks of learned information about a particular concept. Human working memory has a very limited capacity, often presented as "seven, give or take two" (25) and the information contained within it fades very quickly, within seconds, unless it is rehearsed or learned (2, 9). However, the processing of new information by working memory is essential for it to pass into long-term memory (8). Thus working memory is a "bottleneck" for learning (46).

Cognitive load theory (CLT) is an approach to learning and education that prioritizes strategies to account for this bottleneck. Applying CLT allows the most important information to be processed by working memory, in the most efficient way

(39, 46). The theory posits three types of "load" that are placed on working memory. Intrinsic load is the difficulty associated with the material or task to be learned. Multiplying 1,074.7 × 68.961 has a higher intrinsic load than multiplying 2 × 3. Intrinsic load is basically fixed; educators or students can do little to alter it apart from breaking down learning into smaller blocks that represent less intrinsic load. Germane load is the amount of load, or mental effort, being dedicated to the desired learning. In a class of learners, a student who is completely focused and attentive on the class material has a higher germane load than a student who is daydreaming about what to watch on TV. An educator's goal is to maximize germane load, although much of this come from the students themselves. Extraneous load is load that is not related to the desired learning. Simple examples of extraneous load are normally in the form of distractions. In a traditional university lecture, these might be people arriving late and packing away early, somebody typing loudly or a phone ringing. Although these are fairly trivial distractors, they occupy some of the limited space in working memory and so reduce capacity for learning. In addition, learners may have little control over whether or not they become distracted by these sources of extraneous load. However, a significant amount of extraneous load can also come from instructional design (18, 38, 46), and so an educator can improve the learning of their students by reducing these sources of extraneous load. In addition to extraneous load, it is also important for educators to consider working memory overload. Once working memory capacity is exceeded, additional new information simply "bounces off" and is not processed (22).

Human learning is structured to try to account for some of these limitations. For example by "chunking" related pieces of learning together into a single "chunk," the information takes up fewer of the approximately seven "slots" available in working memory than each element would individually. However, chunking is dependent on the availability of previously learned material in long-term memory (4). A simple way of illustrating how chunking works is to think of how learning "times tables" affects basic arithmetic. When asked to solve 12 × 12, most people can instantly answer "144" because this calculation has been stored as one chunk of information in long-term memory. This arises from having learned the 12 times tables at a point in the past. In contrast, most people do not learn a 17-times table, so when they are asked to solve 17 × 17, they break it down into chunks that look like the chunks we have learned and are in our long-term memory, e.g., 7 times tables, 10 times table. We then use and hold those

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chunks in working memory to solve 17×17. Thus we might break 17×17 into $10 \times 17 = 170$ (first chunk), $7 \times 10 = 70$ (second), and $7 \times 7 = 49$ (third). We then need to hold those three while we assemble them into $170 + 70$ (fourth) and then $240 + 49$ (fifth). Chunking is one explanation for the means by which we appear to be able to process significant volumes of complex material (such as learning human physiology) in real time; the processing of this material requires us to retrieve our existing knowledge from long-term memory. When all of the material is completely new and is not represented in long-term memory, then processing is considerably slower.

Lecture presentations, enabled by software such as Microsoft PowerPoint, are still a very common teaching method used in higher education, despite repeated calls for more interactive approaches based on the principles of active learning (e.g., Ref. 14). Many studies have examined the effects of integrating video and animation into lecture and multimedia presentations, and their effects on student recall, learning, satisfaction, and engagement. Multiples studies show that students believe that video and animations are engaging, as well as being good for illustrating difficult concepts (5, 12, 36). Mayer and Moreno (22) showed that learning was improved by the use of educational animations in association with tasks that were specifically linked with the retention of that information. Other studies have indicated that animations are more effective in teaching than still images, especially in the case of teaching dynamic events (12, 30, 42). For example, Williams and Abraham (44) looked at the use of animations to represent a complex chemical pathway. One group of participants saw the animation with audio explaining the pathway, and a control group only heard an audio description. Participants who saw the animation subsequently performed better in a test based on that information than those who had just listened to the audio (44). McClean et al. (23) carried out a similar study. A small group of students were shown an animated three-dimensional protein structure that was used to help explain some information. The structure was moving on a loop like an animated GIF (graphics interchange format), and a second group of students were given the information lacking the animation. Again the students who had viewed the animation were better able to successfully recall information and answer questions (23). Thus an enthusiastic educator seeking to utilize evidence-based approaches to instructional design might reasonably conclude that animations are a useful component of learning materials.

However, other studies have suggested that the use of animations leads to no academic advantage or may in fact impair learning compared with still images (6, 7, 17, 45). Mayer and coworkers (21) developed the "static media hypothesis" after they showed that paper-based static illustrations supported learning more effectively than computer-based animations. Tabbers et al. (40) found there to be no difference between using animations, sound, still images, and text to depict a key idea. They suggested the only advantageous mode of information presentation was to accompany a matching image with sound that was directly related to the main learning objectives (40). They refer to the visual images as a "cue" (for other studies and reviews see Refs. 26–28). A common factor in the above studies is that animations may enhance learning when students are directed to explicitly pay attention to them, and the design and integration of the animation is deliberate and considered for that purpose. However, the mechanisms by which some animations might impair learning have not received as much attention.

Part of the apparent discrepancy between these sets of studies, showing that animations can both impair and enhance learning, may be explained by the "seductive details effect," a phrase first coined by Harp and Mayer in 1998 (14a). In summary, the evidence shows that interesting but irrelevant details impair learning. This has been studied mostly for text and still illustrations, but there is limited literature on animations (31). The more "interesting" the irrelevant details are, the more they impair learning (20). Unsurprisingly, these "seductive details" have been shown, using eye-tracking experiments, to draw attention to themselves and away from material to be learned (32), and the effect is moderated by how relevant the seductive details are to the learned material and the emotional valence of the seductive details (35).

The seductive details effect has been extensively studied, and many authors posit a link between seductive details and extraneous cognitive load, or cognitive overload. However, this link has not been extensively studied. Indeed, a 2020 meta-analysis of the seductive details effect stated, "This cognitive overload assumption is one of several hypotheses posited for the occurrence of the seductive details effect" (37). Two studies have demonstrated that the seductive details effect is moderated by total cognitive load, with seductive details impairing learning more under high load conditions compared with low, but not under low (15, 29). Another study found that participants using a multimedia resource to learn about cognitive load in Chinese experienced a seductive details effect when irrelevant images were added to the resources, and that the participants reported higher cognitive load in the seductive details condition (43). Another study demonstrated that experimental participants with lower working memory capacity were more likely to attend to seductive details (33). However, two meta analyses have been conducted on the seductive details effect, and neither has analyzed cognitive load as a moderator (31, 37), presumably due to a lack of data.

Animations are now built into most software presentation packages, such as Microsoft PowerPoint, and educators can select from libraries of thousands. Advice is often given to include animations to simply make presentations more "engaging" or "visually appealing" (e.g., see Ref. 28). This inclination may be enhanced by the ubiquity of animated images, particularly ".gif" files, as means to attract attention in social media environments. A study of social media sites found that animated GIFs are more "engaging" than other forms of media (3). However, there has been limited research to date on the potential for animations to act as seductive details. Using images specially created using Adobe Photoshop, Tsai and coworkers (41) tested the impact of still versus dynamic illustrations (animations) on the learning of infant milestones. They used a task with low cognitive load and did not find a seductive details effect with either still or dynamic illustrations (41).

In our study, using a basic Microsoft PowerPoint presentation, we tested whether the addition of built-in decorative animations resulted in a seductive details effect on learning. We found that decorative animations impaired recall of STEM (science, technology, engineering, and mathematics) content. Decorative animations were associated with higher mental workload and were themselves harder to remember,

suggesting that they are a source of extraneous cognitive load. We conclude that animations should only be used when they are the focus of learning activities, and not simply to visually enhance learning materials or to prompt engagement.

MATERIALS AND METHODS

This study sought to determine whether animations that are relevant, but decorative, have any impact on recall of STEM content presented in lecture slides. We tested three hypotheses:

- Decorative animations will impair recall compared with still images
- Animations occupy more working memory resource than still images
- Decorative animations are a source of extraneous cognitive load.

This study was carried out on first-year undergraduate STEM students. Ethical approval was obtained from the Swansea University Medical School Ethics Committee (ref. no. 2018–0061). The final experimental protocol was developed following a pilot study.

Studies took place before class using content that was relevant to the class and formulated in conjunction with class coordinators. Students were briefed about the study without explicitly telling them the aims. This briefing included telling them that it was an investigation into different teaching methods and that, although they will not be explicitly tested on the content again, it should help give them a deeper understanding of their topic of study. Participation was voluntary. Participants were told that submitting their answer sheet at the end of the experimental study meant they were giving consent to their data being used. They could withdraw or not participate at any point up to the submission of their sheet. Participants were asked not copy each other to avoid skewed data. All data were anonymous.

Experiment 1 ($n = 96$) was a presentation composed of two parts, *sections A* and *B*. *Section A* was based on the format of a traditional PowerPoint presentation. We did not utilize a presenter (lecturer) for a number of reasons. First, the animations are visual information, and we wished to isolate their effect on the processing of other visual information without the confound of auditory information or additional visual cues provided by a human presenter. Also, there are no standardized lecturers; there is considerable variation in style, clarity, and other aspects of oral presenting. Finally, it is difficult to achieve meaningful double-blinding when using a human presenter. Therefore, a silent PowerPoint presentation was played through automatically. Students were asked to read the content and then follow the instructions given on the slides and the answer sheet.

The instructions for *section A* informed students that they would see the following slides for 30 s and that they were to try to memorize as much information as possible from each slide. Each content slide would be followed by a "blank" for 5 s, followed by a four-option multiple-choice question (MCQ), displayed for 20 s, which students were to try to answer correctly. The structure of this section is shown in Table 1. In total, there were eight (2×4) content slides with either a still image or decorative animation present, alternating every slide for four slides and then flipping, so that every content slide was presented with either a still image or an animation within the session. Each animation or still was only used once. The students were split into two groups and run in separate sessions. The scientific content and order of the slides and MCQs did not change between groups. The only thing that was different between the groups was whether an MCQ was presented with an animated image or a still (see Table 1). Each content slide was used twice, with a different question, but with either still or animated image and a different question. The still images and animations were standard formats randomly chosen from the built-in collection that comes with Microsoft PowerPoint or from Wikimedia Commons. A representative set of slides is available upon request.

Section B aimed to identify the student's ability to recall 10 still images or 10 animated GIFs and then rate their mental effort on a commonly used 9-point scale, where 1 is an extremely low mental effort and 9 is an extremely high mental effort (27). The images were distinct from those used in *section A*. Participants entered responses on a preprinted response sheet. The order of experiments is displayed in Fig. 1.

Experiment 2 ($n = 416$) was a repeat of *section A* of *experiment 1* but using different content (human physiology) designed to control for content-specific effects.

Data analysis. All submitted answer sheets were scored, with a correct MCQ being given "1" mark and each incorrect noted as "0". For *section B*, participant sheets were given one "1" mark for each of the 10 animated and 10 still images that they were able to recall. The data sheets were scored by one researcher (A.P.). A 10% sample was cross checked by the other researcher (P.M.N.). Where ambiguous or inexact answers were given, for example one of the images was a gecko but "lizard" was given, responses were agreed on by A.P. and P.M.N. Data from returned sheets were then transcribed into a Microsoft Excel spreadsheet by one researcher (A.P.), and a 10% sample was cross checked for transcription by the other researcher (P.M.N.). Data were then imported into GraphPad Prism (San Diego, CA). All raw data were normally distributed (D'Agostio and Pearson test, $P > 0.2$ in all cases). In accordance with journal requirements (10), means are reported as $\pm$SD, but plotted as $\pm$SE, since this better represents confidence intervals. Means were compared using t tests. Effect sizes were calculated by subtracting the "still performance" from the "animation performance" and dividing by the pooled standard deviation.

RESULTS

Our data show that, when content was presented with animations, student performance on questions was reduced compared with content presented with still images. As shown in Fig. 2, this was found for both enzyme kinetics and physiology content areas. When compared by paired t test, the difference in performance was significant for both content areas ($P = 0.0004$ for enzyme kinetics, $P = 2 \times 10^{-30}$ for physiology), and when both were combined ($P = 1.3 \times 10^{-32}$). The standardized effect sizes were -0.5 (enzyme kinetics), -0.78 (physiology), and -0.73 (combined).

Question-by-question analysis. To determine whether the above reduction in question performance was driven by performance on individual questions, we analyzed the effect of decorative animations on a question-by-question basis and found that content slides containing animated images were associated with poorer performance on 14 of the 16 questions (Table 2).

Table 1. *The structure and order of the different content slides in section A*

Content Slides	Group 1	Group 2	Question No.
A	S1	G1	*1*
B	G1	S1	*2*
C	S2	G2	*3*
D	G2	S2	*4*
A	G3	S3	*5*
B	S3	G3	*6*
C	G4	S4	*7*
D	S4	G4	*8*

Eight different questions were asked, regarding content (*A—D*) that has been presented alongside either a decorative animation (G) or a still (S).

Fig. 1. Flow chart explaining the ordered structure of the study. GIF, graphics interchange format; MCQ, multiple-choice question.

Recall of animated versus still images. As shown in Fig. 3*A*, the mean number of still images recalled was 6.52 ± 1.313. The mean number of animated images recalled was 4.40 ± 1.638. This difference was significant according to a paired *t* test ($P = 4.9 \times 10^{-17}$). The standardized effect size was −0.82.

Self-perceived mental effort required to recall images. Mental effort was recorded using an established self-report scale of 1–9 (27). The mean effort required to recall the still images was 4.98 ± 1.714. For animated images, it was 5.92 ± 1.753. According to a paired *t* test, the difference between image type was significant ($P = 9.2 \times 10^{-7}$). The standardized effect size was 0.52. Results are shown in Fig. 3*B*.

Relationship between mental effort and image recall. If the higher mental effort required to recall animated images is an explanatory factor for the poorer recall performance, then there should be a relationship between these two variables. To test this, two scores were calculated for each participant. Their performance on the recall of 10 animated images was subtracted from their recall of 10 still images, to create an overall performance difference score. The same approach was used to calculate a mental effort difference score. Using a Spearman rank correlation test, we found a significant, negative correlation between the two scores [$r(90) = -0.3097$, $P = 0.0027$], indicating that a higher difference between self-reported men-

Fig. 2. Performance on multiple-choice question (MCQ) testing content presented alongside animations is lower than performance on MCQ testing content presented alongside still images. Mean performance is shown for two different content areas [enzyme kinetics (*A*) and physiology (*B*)] and then the combined data set (*C*). *$P < 0.05$ (see text for exact *P* values).
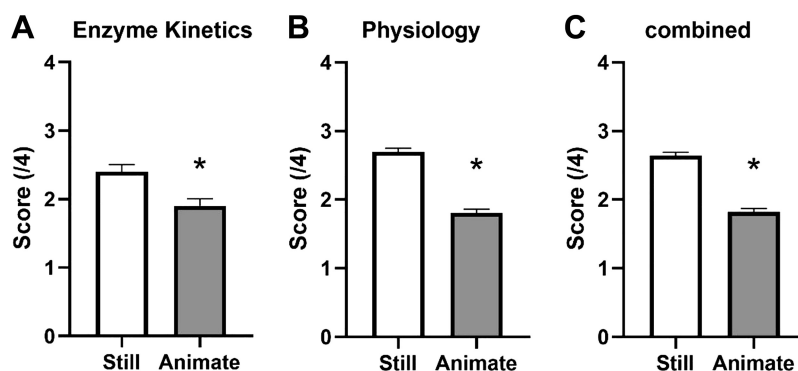
tal effort when recalling animated versus still images is associated with bigger difference in ability to recall animated versus still images.

DISCUSSION

"Decorative" animations are built into common presentation programs such as Microsoft PowerPoint. Here we show that decorative animations cause a "seductive details effect." They are a source of extraneous cognitive load and are associated with an impairment of recall of instructional materials from slides. Student participants showed impaired recall of content when it was presented with a decorative animation compared with a still image. In a separate section, students were also less able to recall animated images compared with still, and this was correlated with higher mental effort being required to recall the animated images. This suggests that the animations occupy more space in working memory compared with still images, increasing mental workload. When animations are then added for decorative purposes, they act as a "seductive detail," attracting attention, but ultimately acting as a source of extraneous cognitive load and impairing recall and thus learning. Much of the existing literature on seductive details posits a link between the negative effects of seductive details and an increase in (extraneous) cognitive load. Here we demonstrate a link between a seductive details effect and increased extraneous load.

Most of the research on seductive details has been on text or still images (29, 31, 32), and the current research indicates that these properties extend to animations. In addition, we extend the range of research on seductive details to include physiology. A recent meta-analysis of the seductive details effect by Sundararajan and Adesope (37) included papers that spanned a wide range of disciplines, although many papers used the original materials from Harp and Mayer (14a) which taught students about lightning. The effect sizes found here were all larger than the mean effect size found by Sundararajan and Adesope (-0.33), suggesting that decorative animations may produce a stronger impairment than other seductive details, such as text. This will be an interesting avenue for future research.

There are a number of practical implications for these findings. Previous studies have looked at the efficacy of using animated images for the teaching of science in higher education. However, these have tended to focus on animations to which students are specifically supposed to pay attention (e.g., Ref. 11), and there has even been a suggestion that such animations reduce cognitive load by reducing the need for learners to hold multiple representations of an image in their working memory (19). One obvious practical implication then would be for instructional design, and instructional designers, to avoid the use of animations that are designed purely to enhance visual appeal and/or engagement.

Tsai et al. (41) do not get a seductive details effect when using animations, or still images, under low load conditions. The fact-heavy nature of STEM teaching, along with the

Table 2. *Question-by-question analysis*

| MCQ | Difference Score | |
	Kinetics	Physiology
1	13.05	31.94
2	21.74	17.89
3	21.74	12.83
4	6.52	40.64
5	−6.52	26.45
6	0.00	33.86
7	2.17	11.01
8	6.52	6.58

Animations were associated with impaired learning on 14/16 questions used. A difference score was calculated by subtracting the percentage of participants who answered correctly with animated images present from the percentage who answered correctly with still images present. MCQ, multiple-choice question.
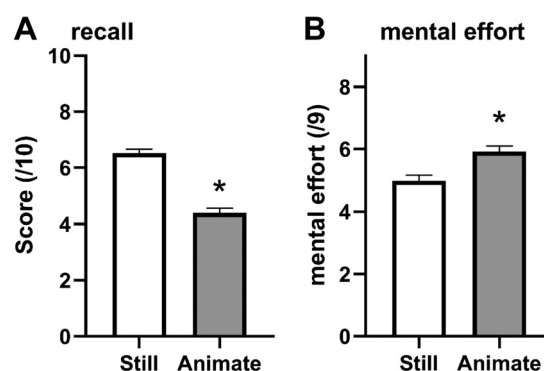

Fig. 3. Recall of animated images is harder than for still images and is correlated with higher mental effort. *A*: participants were shown 10 animated images together for 10 s, then a blank slide for 5 s, and asked to recall as many of the animated images as possible. The same task was repeated for still images. *B*: participants were then asked to rate the mental effort associated with each task. Participants could recall fewer animated images, and this required more mental effort, with a significant negative correlation between the two. *$P < 0.05$.

associated esoteric terminology, likely introduces high intrinsic cognitive load into even introductory courses. Previous research has also identified a stronger effect of seductive details when evaluated under time-limited conditions (31). We deliberately used a time-limited paradigm here to partially reproduce a traditional lecture, in which students have little control over the pace and content of the presentation. This also likely represents a higher load condition.

There are some limitations to this study. First of all, it is difficult to objectively measure cognitive load. This is, in part, because the basic concept is itself a cognitivist construct; there is no anatomical or biochemical marker of cognitive load. Thus most studies use self-report measures, such as the NASA-TLX (National Aeronautics and Space Administration-Task Load Index) or the 9-point scale developed by Paas et al. (27). There are other, perhaps more objective, ways to measure the effort or stress experienced during a learning task. For example, heart rate has been used as a marker of mental effort (26), although this would be challenging under the conditions deployed here.

We collected no demographic or other data from individual participants; to maximize participation we wanted the study to be brief and nonintrusive, conducted in a normal teaching environment rather than a laboratory. This means that we are unable to test for any moderators of the effects that we observed. Previously identified moderators of the seductive details effect include extraversion and self-regulation (31), and these could be an important avenue of future study, although these would need to be balanced against the practical reality of large STEM classes. It is unlikely that these classes could be sorted according to individual demographics, particularly given the number of other variables that influence achievement in higher education (34).

We were not able to directly test the mechanism via which the animated images impaired learning. One obvious implication from the literature on seductive details, but also from other fields, including marketing and the psychology of attention, is that the animations act as a visual cue, drawing attention toward them and away from the material to be learned (3, 19, 32). This could be directly tested in future work using approaches such as eye-tracking (13, 24, 41), possibly in combination with the aforementioned physiological measure of cognitive load (e.g., see Ref. 16).

Finally, there are a number of different variables within this study, and variance within each of them may have influenced the findings. For example the experimental design of our study included the use of four different decorative animations and four different still images. The key difference between these groups is that one group is animated and the other still, but the actual content of both groups of images is necessarily different as well, although we tried to match the content of the two image groups as far as possible. Each image was used twice, for two different subjects. Participants showed greater recall on 14 of the 16 different MCQs when it was testing content that had been paired with a still image rather than a decorative animation, and thus the most parsimonious conclusion is that it is the animation that is impairing recall, rather than differences with any other variable. This conclusion is supported by the results of *section B* and the correlation between performance in *section A* and *section B*.

In summary, decorative animations appear to act as a seductive detail that impairs learning, even though they may appear to enhance the visual appeal of slide presentations. We hope that all STEM educators who read this are given pause for thought before clicking "insert clipart."

DISCLOSURES

No conflicts of interest, financial or otherwise, are declared by the authors.

AUTHOR CONTRIBUTIONS

P.M.N. conceived and designed research; A.P. performed experiments; A.P. and P.M.N. analyzed data; A.P. and P.M.N. interpreted results of experiments; P.M.N. prepared figures; A.P. and P.M.N. drafted manuscript; A.P. and P.M.N. edited and revised manuscript; A.P. and P.M.N. approved final version of manuscript.

REFERENCES

1. **Atkinson RC, Shiffrin RM.** Human memory: a proposed system and its control processes. In: *Psychology of Learning and Motivation*, edited by Spence KW, Spence JT. New York: Academic Press, p. 89–195.

2. **Baddeley A.** Working memory: looking back and looking forward. *Nat Rev Neurosci* 4: 829–839, 2003. doi:10.1038/nrn1201.

3. **Bakhshi S, Shamma DA, Kennedy L, Song Y, de Juan P, Kaye JJ.** Fast, cheap, and good: why animated GIFs engage us. In: *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems*. New York: Association for Computing Machinery, 2016, p. 575–586. doi:10.1145/2858036.2858532.

4. **Bor D, Seth AK.** Consciousness and the prefrontal parietal network: insights from attention, working memory, and chunking. *Front Psychol* 3: 63, 2012. doi:10.3389/fpsyg.2012.00063.

5. **Brame CJ.** Effective educational videos: principles and guidelines for maximizing student learning from video content. *CBE Life Sci Educ* 15: es6, 2016. doi:10.1187/cbe.16-03-0125.

6. **Catrambone R, Seay AF.** Using animation to help students learn computer algorithms. *Hum Factors* 44: 495–511, 2002. doi:10.1518/0018720024497637.

7. **ChanLin L-J.** Animation to teach students of different knowledge levels. *J Instr Psychol* 25: 166–175, 1998.

8. **Cowan N.** Working memory underpins cognitive development, learning, and education. *Educ Psychol Rev* 26: 197–223, 2014. doi:10.1007/s10648-013-9246-y.

9. **Cowan N.** Working memory maturation: can we get at the essence of cognitive growth? *Perspect Psychol Sci* 11: 239–264, 2016. doi:10.1177/1745691615621279.

10. **Curran-Everett D, Benos DJ.** Guidelines for reporting statistics in journals published by the American Physiological Society. *Am J Physiol Heart Circ Physiol* 287: H447–H449, 2004. doi:10.1152/ajpheart.00478.2004.

11. **Daly CJ, Bulloch JM, Ma M, Aidulis D.** A comparison of animated versus static images in an instructional multimedia presentation. *Adv Physiol Educ* 40: 201–205, 2016. doi:10.1152/advan.00053.2015.

12. **Dash S, Kamath U, Rao G, Prakash J, Mishra S.** Audio-visual aid in teaching "fatty liver". *Biochem Mol Biol Educ* 44: 241–245, 2016. doi:10.1002/bmb.20935.

13. **Ferrari GRA, Möbius M, van Opdorp A, Becker ES, Rinck M.** Can't look away: an eye-tracking based attentional disengagement training for depression. *Cognit Ther Res* 40: 672–686, 2016. doi:10.1007/s10608-016-9766-0.

14. **Freeman S, Eddy SL, McDonough M, Smith MK, Okoroafor N, Jordt H, Wenderoth MP.** Active learning increases student performance in science, engineering, and mathematics. *Proc Natl Acad Sci USA* 111: 8410–8415, 2014. doi:10.1073/pnas.1319030111.

14a.**Harp SF, Mayer RE.** How seductive details do their damage: a theory of cognitive interest in science learning. *J Educ Psychol* 90: 414–434, 1998. doi:10.1037/0022-0663.90.3.414.

15. **Korbach A, Brünken R, Park B.** Learner characteristics and information processing in multimedia learning: a moderated mediation of the seductive details effect. *Learn Individ Differ* 51: 59–68, 2016. doi:10.1016/j.lindif.2016.08.030.

16. **Krejtz K, Duchowski AT, Niedzielska A, Biele C, Krejtz I.** Eye tracking cognitive load using pupil diameter and microsaccades with fixed gaze. *PLoS One* 13: e0203629, 2018. doi:10.1371/journal.pone.0203629.

17. **Large A, Beheshti J, Breuleux A, Renaud A.** Effect of animation in enhancing descriptive and procedural texts in a multimedia learning

environment. *J Am Soc Inf Sci* 47: 437–448, 1996. doi:10.1002/(SICI)1097-4571(199606)47:6<437:AID-ASI4>3.0.CO;2-W.

18. **Leppink J, van den Heuvel A.** The evolution of cognitive load theory and its application to medical education. *Perspect Med Educ* 4: 119–127, 2015. doi:10.1007/s40037-015-0192-x.

19. **Lin L, Atkinson RK.** Using animations and visual cueing to support learning of scientific concepts and processes. *Comput Educ* 56: 650–658, 2011. doi:10.1016/j.compedu.2010.10.007.

20. **Mayer RE, Griffith E, Jurkowitz ITN, Rothman D.** Increased interest-ingness of extraneous details in a multimedia science presentation leads to decreased learning. *J Exp Psychol Appl* 14: 329–339, 2008. doi:10.1037/a0013835.

21. **Mayer RE, Hegarty M, Mayer S, Campbell J.** When static media promote active learning: annotated illustrations versus narrated animations in multimedia instruction. *J Exp Psychol Appl* 11: 256–265, 2005. doi:10.1037/1076-898X.11.4.256.

22. **Mayer RE, Moreno R.** Animation as an aid to multimedia learning. *Educ Psychol Rev* 14: 87–99, 2002. doi:10.1023/A:1013184611077.

23. **McClean P, Johnson C, Rogers R, Daniels L, Reber J, Slator BM, Terpstra J, White A.** Molecular and cellular biology animations: devel-opment and impact on student learning. *Cell Biol Educ* 4: 169–179, 2005. doi:10.1187/cbe.04-07-0047.

24. **Mele ML, Federici S.** Gaze and eye-tracking solutions for psycholog-ical research. *Cogn Process* 13, Suppl 1: S261–S265, 2012. doi:10.1007/s10339-012-0499-z.

25. **Miller GA.** The magical number seven plus or minus two: some limits on our capacity for processing information. *Psychol Rev* 63: 81–97, 1956. doi:10.1037/h0043158.

26. **Mukherjee S, Yadav R, Yung I, Zajdel DP, Oken BS.** Sensitivity to mental effort and test-retest reliability of heart rate variability measures in healthy seniors. *Clin Neurophysiol* 122: 2059–2066, 2011. doi:10.1016/j.clinph.2011.02.032.

27. **Paas F, Tuovinen JE, Tabbers H, Van Gerven PWM.** Cognitive load measurement as a means to advance cognitive load theory. *Educ Psychol* 38: 63–71, 2003. doi:10.1207/S15326985EP3801_8.

28. **Parette HP, Hourcade JJ, Boeckmann NM, Blum C.** Using Microsoft PowerPoint to support emergent literacy skill development for young children at-risk or who have disabilities. *Early Child Educ J* 36: 233–239, 2008. doi:10.1007/s10643-008-0275-y.

29. **Park B, Moreno R, Seufert T, Brünken R.** Does cognitive load mod-erate the seductive details effect? A multimedia study. *Comput Human Behav* 27: 5–10, 2011. doi:10.1016/j.chb.2010.05.006.

30. **Pollock E, Chandler P, Sweller J.** Assimilating complex information. *Learn Instr* 12: 61–86, 2002. doi:10.1016/S0959-4752(01)00016-0.

31. **Rey GD.** A review of research and a meta-analysis of the seductive detail effect. *Educ Res Rev* 7: 216–237, 2012. doi:10.1016/j.edurev.2012.05.003.

32. **Rey GD.** Seductive details and attention distraction—an eye tracker experiment. *Comput Human Behav* 32: 133–144, 2014. doi:10.1016/j.chb.2013.11.017.

33. **Sanchez CA, Wiley J.** An examination of the seductive details effect in terms of working memory capacity. *Mem Cognit* 34: 344–355, 2006. doi:10.3758/BF03193412.

34. **Schneider M, Preckel F.** Variables associated with achievement in higher education: A systematic review of meta-analyses. *Psychol Bull* 143: 565–600, 2017. doi:10.1037/bul0000098.

35. **Schneider S, Nebel S, Rey GD.** Decorative pictures and emotional design in multimedia learning. *Learn Instr* 44: 65–73, 2016. doi:10.1016/j.learn-instruc.2016.03.002.

36. **Stockwell BR, Stockwell MS, Cennamo M, Jiang E.** Blended learning improves science education. *Cell* 162: 933–936, 2015. doi:10.1016/j.cell.2015.08.009.

37. **Sundararajan N, Adesope O.** Keep it coherent: a meta-analysis of the seductive details effect. *Educ Psychol Rev.* In press. doi:10.1007/s10648-020-09522-4.

38. **Sweller J, Chandler P.** Why some material is difficult to learn. *Cogn Instr* 12: 185–233, 1994. doi:10.1207/s1532690xci1203_1.

39. **Sweller J, van Merrienboer JJG, Paas FGWC.** Cognitive architecture and instructional design. *Educ Psychol Rev* 10: 251–296, 1998. doi:10.1023/A:1022193728205.

40. **Tabbers HK, Martens RL, van Merriënboer JJ.** Multimedia instruc-tions and cognitive load theory: effects of modality and cueing. *Br J Educ Psychol* 74: 71–81, 2004. doi:10.1348/000709904322848824.

41. **Tsai M-J, Wu A-H, Chen Y.** Static and dynamic seductive illustration effects on text-and-graphic learning processes, perceptions, and outcomes: evidence from eye tracking. *Appl Cogn Psychol* 33: 109–123, 2019. doi:10.1002/acp.3514.

42. **Tversky B, Morrison JB, Betrancourt M.** Animation: can it facilitate? *Int J Hum Comput Stud* 57: 247–262, 2002. doi:10.1006/ijhc.2002.1017.

43. **Wang Z, Sundararajan N, Adesope OO, Ardasheva Y.** Moderating the seductive details effect in multimedia learning with note-taking. *Br J Educ Technol* 48: 1380–1389, 2017. doi:10.1111/bjet.12476.

44. **Williamson VM, Abraham MR.** The effects of computer animation on the particulate mental models of college chemistry students. *J Res Sci Teach* 32: 521–534, 1995. doi:10.1002/tea.3660320508.

45. **Wright P, Milroy R, Lickorish A.** Static and animated graphics in learning from interactive texts. *Eur J Psychol Educ* 14: 203–224, 1999. doi:10.1007/BF03172966.

46. **Young JQ, Van Merrienboer J, Durning S, Ten Cate O.** Cognitive Load Theory: implications for medical education: AMEE Guide No. 86. *Med Teach* 36: 371–384, 2014. doi:10.3109/0142159X.2014.889290.