

Article

The Value of Animations in Biology Teaching: A Study of Long-Term Memory Retention

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Previous work has established that a narrated animation is more effective at communicating a complex biological process (signal transduction) than the equivalent graphic with figure legend. To my knowledge, no study has been done in any subject area on the effectiveness of animations versus graphics in the long-term retention of information, a primary and critical issue in studies of teaching and learning. In this study, involving 393 student responses, three different animations and two graphics—one with and one lacking a legend—were used to determine the long-term retention of information. The results show that students retain more information 21 d after viewing an animation without narration compared with an equivalent graphic whether or not that graphic had a legend. Students' comments provide additional insight into the value of animations in the pedagogical process, and suggestions for future work are proposed.

INTRODUCTION

There is a fairly extensive literature arguing that animations are more effective than static sequential images for teaching dynamic events (Pollock *et al.*, 2002; Tversky and Morrison, 2002). In spite of an increasing availability of animations, particularly as part of textbook packages, there has been little research into the value of animations versus static illustrations in science teaching. Stith (2004) has reviewed this issue with a focus on cell biology teaching animations. In that review, Stith reports on an initial study where, after a formal lecture on cell death (apoptosis) illustrated with static graphics, some students were subsequently shown an animation after which all students were tested. The students who viewed the animation scored significantly higher on the test than those who had not viewed the animation. McClean *et al.* (2005) did a more comprehensive study in which small groups of students viewed a three-dimensional animation of protein synthesis in various combinations of individual study and a formal lecture versus individual study followed by a lecture without the animation. In all cases, the groups viewing the animation scored significantly higher in the follow-up test than the group that did not view it. In a study using animations in a chemistry course, where students

have difficulty with mental models about the particulate nature of matter, students obtained significantly higher test scores when the animation was viewed as part of a lecture or as a supplement to individual study compared with a control group of students who did not have access to the animation (Williams and Abraham, 1995). In keeping with those studies, it was revealed that students understood a complex signal transduction pathway better after viewing a narrated animation compared with a graphic with an equivalent legend (O'Day, 2006a). Thus, the few studies that have been done indicate that animations provide students with insight into biological processes in a way that traditional lecturing and static graphics do not.

An extensive review of the literature covering all educational disciplines has indicated that there are certain parameters that need to be considered when making a teaching animation (O'Day, 2006a, 2006b). Of relevance here is that animations are most effective when text is adjacent to important structures and is spoken simultaneously to reinforce the learning process ("spatial contiguity effect," "multimedia effect," and "personalization effect," respectively; Mayer, 2003). Many biological animations that are freely available online do not include narratives. Often, these animations are intended for in-class use with the instructor providing the narrative (Stith, 2004; McClean *et al.*, 2005). Students who access these animations online do not have the benefit of the instructor's narration. However, research in other disciplines indicates that animations and graphics

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with a spoken or written narrative are more effective than those lacking a narrative (e.g., Mayer, 2003).

In spite of the amount of research that has been done on the value of animations as tools of pedagogy, no study has yet addressed the issue of retention of learned information in any area. The primary goal of this study was to determine whether short- and long-term memory retention are greater with an animation compared with a graphic regardless of the availability of a narrative. Data are presented here using several different types of animations and graphics that support the value of animations in the learning process and that reveal for the first time that students retain significantly more information 21 d after viewing animations lacking a narration compared with graphics whether or not a legend was available.

MATERIALS AND METHODS

Animations, Graphics, and Programs

Animations from three different sources were used, each with different parameters (Table 1). For comparative analyses, graphics were constructed for two of them. The animation I produced for this study (cholesterol uptake) was made using PowerPoint 2003 (Microsoft Office Standard Edition 2003 for Students and Teachers; Microsoft, Redmond, WA), and it was captured and converted into a movie format by using Camtasia Studio 2.1.1 (TechSmith, Okemos, MI) as outlined previously (O'Day, 2006a). The graphic for that animation was produced by exporting PowerPoint slides as jpg files (O'Day, 2006a). For the apoptosis analysis, original graphics were drawn by the author using CorelDraw 7.0 (Corel, Ottawa, Ontario, Canada) to generate images essentially identical to those in the animation (Figure 1). All of these animations and graphics were provided online, and students were given specific links to access them (Table 2). Immediately after the exercise, the links were shut down until after the study was over, so that students would not be able to access the information before the retention part of the study. Statistical analyses of the data were performed using GraphPad Prism, version 4.03 for Windows (GraphPad Software, San Diego, CA) as detailed previously (O'Day, 2006a).

General Methodology

The viewing of the animations and graphics as well as the completion of the evaluations was carried out under the supervision of two

Ph.D. teaching assistants (TAs) without my participation. Undergraduate students in five different tutorial groups in two different courses (BIO380, Human Development, and BIO315HF, Advanced Cell Biology) were given specific instructions, and they were allowed to view either an animation or graphic. After the specified viewing time, each student was handed a questionnaire that was then completed as directed. For the retention analyses, students were given only part II (i.e., the specific questions) of the same questionnaire 21 d later.

Instructions Given to Students and TAs

Each TA was provided with a specific script for either the animation or graphic that was to be viewed, and he or she was asked to carry out the instructions exactly as indicated. The exact text that was provided to the TAs for the apoptosis evaluation for both the graphic and animation, respectively, is provided in Supplemental Material 1. Minor variations in the text were included that were specific to whether the graphic or animation was being viewed. The text also was varied slightly based on the specific animation/graphic under analysis (e.g., length of time provided; Table 2).

Questionnaires

For consistency, the questionnaire design followed that of a previous study (O'Day, 2006a). An example of the full questionnaire that was used for the apoptosis analysis is shown in Supplemental Material 2. For each evaluation, only the questions were changed. The questions for the influenza virus evaluation are provided as Supplemental Material 3, whereas those for the cholesterol uptake evaluation are shown in Supplemental Material 4. For the retention analysis, only the 10 specific questions about the animation or graphic were provided (part II).

RESULTS

Questionnaire Responses

The anonymous evaluations were carried out in five different tutorials in two different junior (third-year) courses (BIO315HF, Advanced Cell Biology, and BIO380HF, Human Development) with 213 students participating in the initial evaluation and 180 students filling out questionnaires for the memory retention analyses. The lower number for the retention evaluation resulted from students dropping the

Table 1. Sources of and details about the animations and graphics used in this study

Title	Animation	Graphic
Cholesterol uptake	http://www.utm.utoronto.ca/~w3bio380/anib.htm . This is an author-developed animation with the narrative produced using PowerPoint and Camtasia Studio as described previously (O'Day, 2006a).	http://www.utm.utoronto.ca/~w3bio380/picb.htm . This is an author-produced graphic with the legend produced using PowerPoint and CorelDraw 7.0 as described previously (O'Day, 2006a).
Apoptosis	http://www.whfreeman.com/lodish4e/content/ld23/ld23an01a.htm . This unnarrated animation is one of many high-quality teaching animations produced for Lodish <i>et al.</i> (2000).	http://www.utm.utoronto.ca/~w3bio380/pic.htm . This author-produced graphic was made using CorelDraw 7.0 as described previously (O'Day, 2006a). An attempt was made to make the graphic images identical to those presented in the apoptosis video (see Figure 1).
Influenza virus	http://www.learner.org/channel/courses/biology/archive/animations/hires/a_infect8_h.html . This narrated animation was produced by Annenberg Media Learner.org, an online company that provides resources for teachers.	

course before the retesting. Seventeen (7.4%) of the original questionnaires were rejected based on incorrect filling out of part I. 1. (i.e., incorrectly indicated what they had viewed or whether they viewed the animation or graphic less than three times within the allotted time). The answers to each of the specific questions in part II were graded, and the marks for each respondent were totaled. The mean and SE of the

mean were then calculated for each group and analyzed statistically as detailed previously (O'Day, 2006a). Once the study was completed and the course was over, the final mean grades for each tutorial group were analyzed, showing that there was no significant difference in grades between the tutorial groups in each course, and supporting the validity of the results that were obtained in the study.

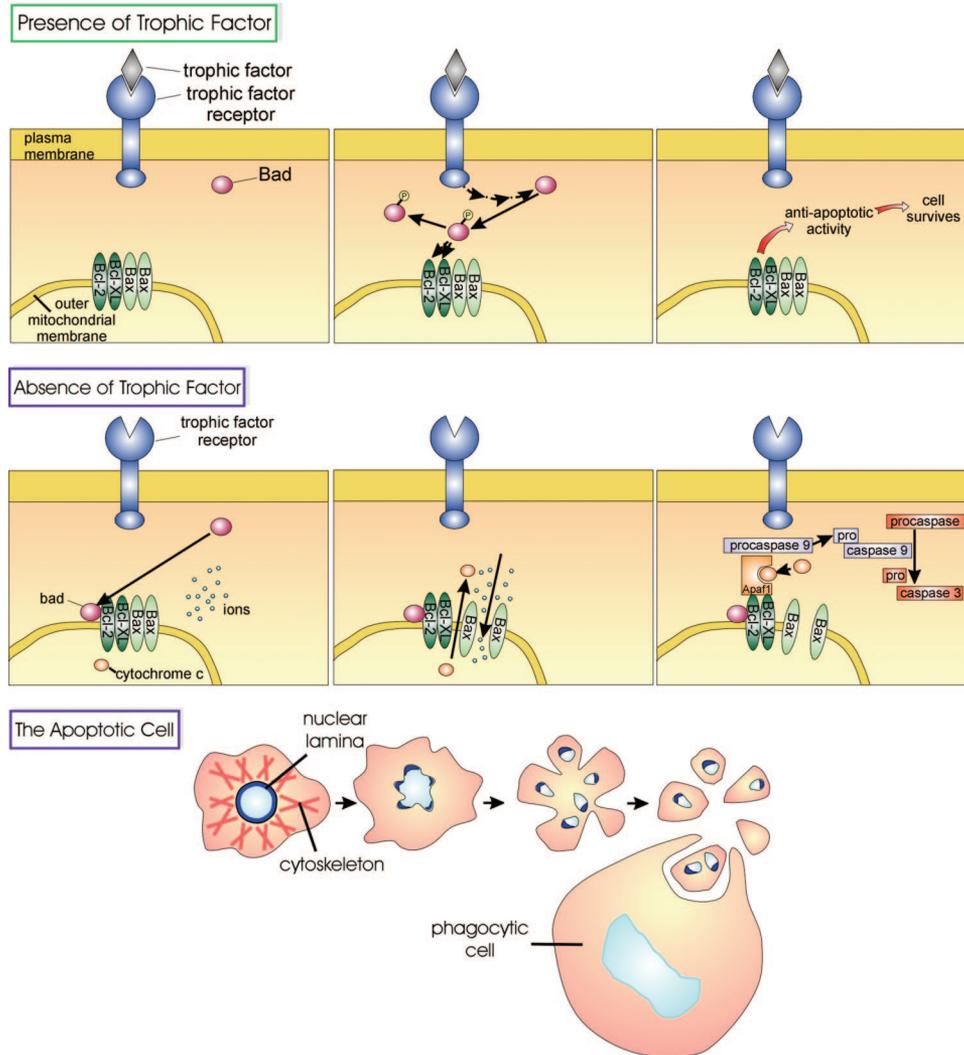


Figure 1. Graphic used in the apoptosis study. CorelDraw 7.0 was used to replicate the major events in the apoptosis animation (<http://www.whfreeman.com/lodish4e/content/1d23/1d23an01a.htm>) as a stand-alone graphic.

Table 2. Animations and graphics used in this study

Title	Animation length (s)	Narrated?	Graphic?/legend?	Viewing time (min)	Complexity
Cholesterol uptake ^a	~97	No	Yes/yes	8	Simple
Apoptosis	~100	No	Yes/no	10	Moderately complex
Influenza virus ^a	~40	No	No/no	5	Moderately complex

^a The cholesterol uptake and influenza virus animations are narrated, but the sound was not activated for this study.

Short- and Long-Term Retention

The attributes of each graphic and animation are summarized in Table 2. The results of the short-term and long-term retention analyses are shown in Figure 2. For the groups learning about apoptosis, neither the graphic nor animation had a written or oral narrative provided. In the initial responses to the questions from the group viewing the apoptosis graphic, the students got $58.1 \pm 0.353\%$ of the questions correct (Figure 2, apoptosis). When the students were tested 21 d later, they got $35.8 \pm 0.318\%$ of the questions correct.

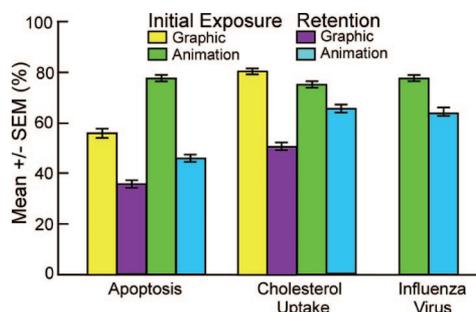


Figure 2. Questionnaire results for initial and retention analysis. Students who viewed the apoptosis graphic and animation were tested immediately (initial exposure: graphic and animation) and 21 d later (retention: graphic and animation). Similarly, students who viewed the cholesterol uptake graphic and animation were tested immediately (initial exposure: graphic and animation) and 21 d later (retention: graphic and animation). A single group that viewed the influenza virus animation was tested immediately (initial exposure: animation) and after 21 d (retention: animation). The mean \pm SEM were calculated for the total marks resulting from student answers to the specific questions in part II of the questionnaires (see Supplemental Material 2–4 for the specific questions).

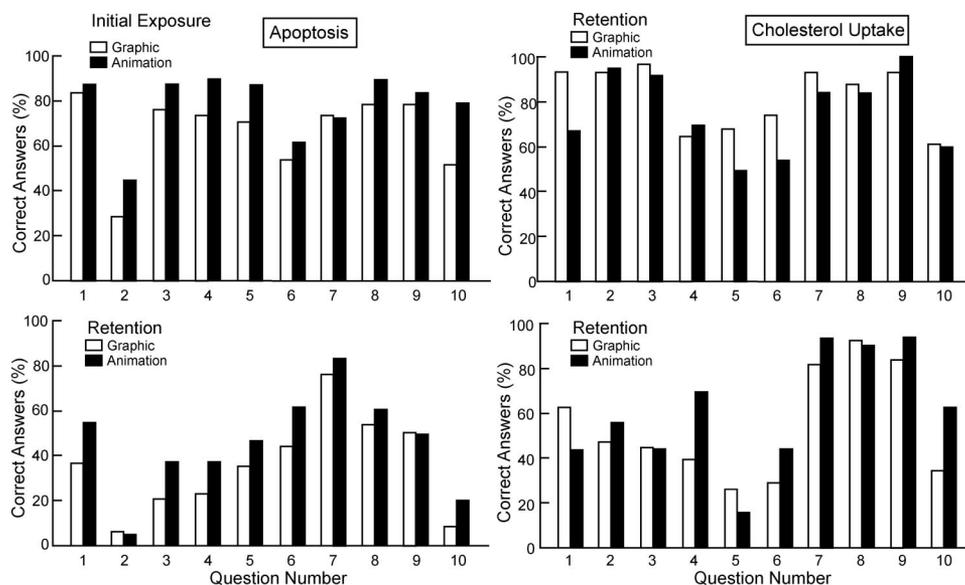


Figure 3. Questionnaire results for specific questions. Students who viewed the apoptosis and the cholesterol uptake graphics and animations were tested immediately (initial exposure: graphic and animation) and after 21 d (retention: graphic and animation). The mean correct answers for each question in part II of the questionnaires (see Supplemental Material 2–4 for the specific questions) for each condition are shown.

Those viewing the apoptosis animation initially got $77.9 \pm 0.221\%$ of the answers correct in part II. After 3 wk, their average mark dropped to $43 \pm 0.304\%$. For the cholesterol uptake group who viewed a graphic with a detailed figure legend, the mean mark after viewing the graphic was $80.6 \pm 0.136\%$, which decreased to $50.0 \pm 0.308\%$ after 21 d (Figure 2, cholesterol uptake). For the cholesterol uptake animation for which narration was not made available, the mean mark of the students was initially $75.0 \pm 0.249\%$, but it decreased to $63.1\% \pm 0.303$ after testing 21 d later. Due to the limited number of tutorials that were available for the analyses, it was not possible to compare a graphic with the influenza virus animation. The influenza virus animation was viewed without the available narration, leading to an initial mean mark of $77.9 \pm 0.221\%$ (Figure 2, influenza virus). After 21 d, those who studied the influenza virus animation obtained an average grade of $61.9 \pm 0.354\%$ on retesting. All of the means were significantly different from each other ($P < 0.05$) except for the means for the cholesterol uptake animation for which the original and retention scores were not deemed to be significantly different.

Retention on Individual Questions

Apoptosis. Using Stith (2004) as a guide, three of the apoptosis questions could be considered “definition” or rote (questions 1, 6, and 7). The remaining questions either dealt with “location of events” or “order” of events. The results from the initial questionnaires indicated that students who viewed the animation without narration scored higher than those who viewed the graphic lacking a legend on all questions except question 7 (Figure 3, apoptosis, initial exposure). Initial mean grades of $>80\%$ were obtained for questions 1, 3, 4, 8, and 9 by students who saw the animation. The biggest differential was seen for question 10. For the reten-

tion, the scores were highest for the animation group for all questions but questions 2 and 9 (Figure 3, apoptosis, retention). The biggest differentials were seen with questions 1, 3–6, and 10. Students scored extremely poorly on questions 2 and 10 for both the graphic and animation.

Cholesterol Uptake. Based on the classification used by Stith (2004), three of the cholesterol uptake questions (1, 7, and 9) could be considered definition or rote. Only question 2 clearly dealt with location of events, whereas the remaining questions (3–6, 8, and 10) dealt with order of events. There was less consistency in the results from question to question between students who viewed the animation and those who viewed the graphic for cholesterol uptake (Figure 3, cholesterol uptake, initial exposure). For the animation, students scored slightly higher for only two questions (4 and 9), but they essentially scored the same as those who viewed the graphic for questions 2 and 10. Students who viewed the graphic scored higher on six questions (1, 3, 5–8). After 21 d, the results shifted markedly with students who had viewed the animation scoring highest on a total of six questions (2, 4, 6, 7, 9, and 10) while scoring essentially the same as those who viewed the graphic on two questions (3 and 8; Figure 3, cholesterol uptake, retention). Those who viewed the graphic scored higher on only two questions (1 and 5) with the poorest retention for all questions being seen with question 5.

Summary of Responses to Questionnaire with Student Comments

In response to the question (part III, 1) "Did you find the material provided a useful learning experience?", 80.9% of the total respondents answered "yes" (78.8% for the animation and 84.7% for the graphic). About 12% (12.9% for animation and 9.7% for graphic) responded "no," and 7.4% (8.3% for animation and 5.6% for graphic) had no opinion. All who answered "no" responded as requested to part III, 2, essentially reiterating various points raised in part III, 3 as indicated below. In all of the responses only two negative comments were received: "We should have been paid to do this" and "This tutorial was a waste of time. I could have been sleeping."

Essentially half of the respondents (49% total, 52.3% animation, and 43.2% graphic) wrote comments in part III, 3. It was difficult to summarize some of the students' comments due to lack of clarity or focus of the response; however, some general trends were observed. Some comments centered on the lack of narration (10.3% of respondents) in the animations, but this was a much lower level than expected. Many (54%) expressed their opinion in various ways that animations are a useful tool for learning the complex sequence of events:

"I really enjoy animation as a means of studying/learning. I feel that it provides a different way of visualizing the process."

"Although the animation didn't explain 'everything,' it served a GREAT purpose in laying out basic and fundamental steps in apoptosis."

"... especially useful for remembering the order of events."

Some students (22.7%) indicated the value of animations in getting right to the point compared with reading long tracts of text or reviewing static graphics, "... especially when you're tired ..."; "... more efficient to learn complicated processes ... than trying to work out visually what is meant from the text." Or, they argued that animations serve a specific use in the study process such as, "... cramming for a test"; "... afterward one can study from the text with the overall process clear in your mind." One student expressed the idea: "This was a good way to see how much info could be remembered without having prior knowledge of the topic."

Of all of the student responses, only one student expressed concern about the value of animations in the learning process: "I question whether this method promotes long-term memory of events." This point was interesting, because it was never addressed what the focus of the study was. Alternatively, that same student also stated animations are "... excellent for revision and visualization," a point addressed by others. There were other singleton comments (e.g., "apoptosis animation should have been presented in two parts" and "protein cleavage was not clear in apoptosis animation") and some technical issues (e.g., size of text, the need for more labels, "Video not large enough to see details") that can provide insight into how such animations and graphics are developed for and presented to students. Two students offered some valid insight: "Discrete animations don't allow for linking between events" and "A good learning method would be to have integrated the animation with follow-up questions ... " during lecture.

DISCUSSION

Animations provide a valuable way to communicate dynamic, complex sequences of biological events more effectively than text or a static graphic (Stith, 2004; McClean *et al.*, 2005; O'Day, 2006a). We are currently teaching an electronic generation of students, individuals whose everyday life is primarily based on auditory and visual communication. Their comments here and in a previous study indicate that they prefer having animations in lieu of reading the textbook (O'Day, 2006a). Although this may be anathema to teachers, it is a reality of academic life that needs to be considered as we develop new courses and curricula. If animations can assist students' learning, then developing more pedagogically meaningful animations to include in our teaching repertoires is worth considering. Research into the pedagogical value of biological animations in the sciences can serve as a guide to developing such animations.

I am not aware of any studies that have been done previously comparing the value of animations versus static graphics in long-term memory retention for any discipline. It is well established that memory of specifics declines over time. Originally defined by Hermann Ebbinghaus in 1885, this "forgetting curve" is a general property of essentially all retrospective memory (Hicks *et al.*, 2000). The forgetting curve or decline of memory retention over time is essentially logarithmic with a fast early phase of forgetting followed by a progressively slower phase. In educational terms without relearning, most students will remember ~25% of learned information after a week and ~21% after 2 to 4 wk. In this

study, "spaced retention" was evaluated: the ability to remember facts and visual information over a specific period of time (21 d). By projection from the forgetting curve, students would be expected to retain around 21% of the originally learned information from both the animations and graphics. However, based on those projections, the memory retention demonstrated here was much greater than expected in all cases.

As expected, forgetting did occur over time for all cases (Figure 2). For the two different graphics that were viewed, the level of long-term retention was approximately 60% (apoptosis) to >200% (cholesterol uptake) higher than the expected ~21% retention based upon general forgetting curve data. These higher retention levels are likely due, in part, to the nonrandom nature and the relevance of the information that was presented to the target audience. These results also indicate that the presence of a figure legend (cholesterol uptake) enhances long-term memory retention. The retention data were even more impressive with the groups who viewed the animations. In both comparative cases, the retention of information by those who viewed the animation exceeded that of the groups who viewed the graphics whether or not a figure legend was provided. Thus, the retention levels were 204% (apoptosis) to 300% (cholesterol uptake) higher than expected based on the basic forgetting curve and 83–79% higher than the comparative graphic, respectively. The results with the influenza animation supported this higher-level retention after viewing an animation. These results support the value of visuals in general in the learning of biological information, and they suggest that animations can provide a better learning experience, leading to greater long-term retention of that learned information.

In his study, Stith (2004) compared the correct responses to specific questions by groups viewing the apoptosis animation versus students who did not. Stith's data suggested that questions involving rote memory (definition) did not benefit from the animation, but those involving dynamic processes (order or location of events) did benefit. The evaluation of specific questions here partly supported this idea for cholesterol uptake, but overall did not support this idea. For example, the poorest retention was seen with two questions (2, apoptosis and 5, cholesterol uptake), but examination of those questions versus the other questions as to difficulty, question type, or complexity did not yield any insight into a potential cause. The current results then suggest that animations lead to better memory retention regardless of the nature of the material that is being learned. This conclusion clearly needs much more in-depth research to validate it. Although the intent and design of our experiments were different from those of Stith (2004), in retrospect it would have been useful to have used Stith's questionnaire in this study. In the future, more emphasis should be put on the careful design of questionnaires with well-defined, type-specific questions (e.g., rote vs. sequence of events vs. interrelationships of components) that might provide more critical insight into when animations should be used over static graphics or text. The formulation of such questions will require a firm grounding in models of learning and memory. Rather than just using multiple-choice questionnaires, it also might be wise to ask students to write a short synopsis of

what they learned to determine whether they are truly understanding events or simply regurgitating key points.

Narration is considered to be an important attribute of educational animations (Sweller, 1994; Lowe, 2003; Mayer, 2003). As a result, it was expected that the majority of students would complain about a lack of narrative in the presented material, but only a small number of students made any comments about the lack of a narrative or figure legend (10.3% of respondents). The question still remains: Is a narrative a critical component of life science animations? This is an important issue, because many biological animations are developed without a narrative for specific, complementary use in lectures. Because many of these animations are freely available online, it is important to understand the implications of their use by students who may not have access to the lecture component. More importantly, adding a narrative to an animation not only involves additional steps but also potentially increases the size of animation files, compromising their effectiveness for online teaching and learning. For these and other reasons, the value of a verbal narrative in animations was compared with static graphics (figures) that either had or lacked a written narrative (legend). Although the subject matter of the presentations differed, the results are suggestive. Based on studies in other disciplines showing the value of a proper narrative, the expected result was that the three separate cases of unnarrated animations in this study would all lead to lower mean marks compared with a previous equivalent study with a narrated animation (87.5%; O'Day, 2006). In keeping with this, the mean initial retention average (76.9%) for the three unnarrated animations used in this study was ~10% less than observed previously, supporting the view that narration is a valuable, if not essential, component in biological animations. Although no previous studies seem to have been conducted on the value of figure legends, in this study the group viewing the graphic with a legend obtained a much higher mean grade (80.6%, cholesterol uptake) compared with those who viewed the graphic lacking a legend (58.1%; apoptosis). Viewing the figure with a legend also led to slightly higher initial marks than the respective unnarrated animation (75.0%; cholesterol uptake). These suggestive data support the widely held view that a written (graphic data or figures) or verbal narrative (animations) enhances the pedagogical value of visually presented information. However, future research that focuses on a single subject (e.g., cholesterol uptake) with narrated versus unnarrated animations compared with graphics with and without an equivalent legend would strengthen these tentative conclusions.

Student feedback is useful in assessing the pedagogical value of animations and graphics (O'Day, 2006a). The student comments in the present study were similar to those expressed in a previous study, and they raise some interesting points (O'Day, 2006a). Students enjoy animations as a change from reading text and attempting to interpret graphics. Biology is a visual subject often involving complex sequences of events. Animations provide one way of communicating such complex sequences clearly and efficiently. To paraphrase the idea expressed by several students, "after viewing the animation, reading the textbook becomes easier and more enlightening."

This study provides evidence that animations lead to greater long-term memory retention than simple graphics. This is an important conclusion that needs further research not only to verify it but also to understand why animations enhance learning retention. Are animations more effective simply because they are more engaging to students than simple text or static graphics, or do they truly lead to deeper learning? The study of the value of animations in the life sciences is fundamentally in its infancy. Currently, a diversity of animations is available online (e.g., <http://www.utm.utoronto.ca/~w3cellan/>) or as part of textbook packages. For those who are interested in developing their own animations, Heyden (2004) has reviewed the various programs, their attributes, and their use in producing teaching animations and has listed complementary resources. More recently, a simple animation technique has been discussed that both students and teachers can use to easily develop their own high-quality, effective teaching animations (O'Day, 2006a). With all of these available resources, there is an opportunity for instructors to carry out further studies on the value of animations in life science teaching. Well-formulated hypotheses and well-designed experiments will go a long way to providing insight into the true value of animations as pedagogical tools.

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