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Article

Animated Cell Biology: A Quick and Easy Method for Making Effective, High-Quality Teaching Animations

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There is accumulating evidence that animations aid learning of dynamic concepts in cell biology. However, existing animation packages are expensive and difficult to learn, and the subsequent production of even short animations can take weeks to months. Here I outline the principles and sequence of steps for producing high-quality PowerPoint animations in less than a day that are suitable for teaching in high school through college/university. After developing the animation it can be easily converted to any appropriate movie file format using Camtasia Studio for Internet or classroom presentations. Thus anyone who can use PowerPoint has the potential to make animations. Students who viewed the approximately 3-min PowerPoint/Camtasia Studio animation "Calcium and the Dual Signalling Pathway" over 15 min scored significantly higher marks on a subsequent quiz than those who had viewed still graphics with text for an equivalent time. In addition, results from student evaluations provided some data validating the use of such animations in cell biology teaching with some interesting caveats. Information is also provided on how such animations can be modified or updated easily or shared with others who can modify them to fit their own needs.

INTRODUCTION

Animations can bring complex cellular events to life and give students insight into dynamic events that static graphics cannot. Cell biology involves many dynamic processes that lend themselves to animation, and there is accumulating evidence that animations are more effective than static sequential images in the learning process (Nicholls and Merkel, 1996; Pollock *et al.*, 2002). Already many animations exist that demonstrate fundamental events but the vast majority of these are offerings available only upon adoption of a specific textbook. Many free animations are available including high-quality animations on molecular biology and metabolism from the Virtual Cell (VCell) animation project (McClean *et al.*, 2005). Stith (2004) has produced, alone and in conjunction with others, many excellent, complex animations on topics such as enzyme activity, cell movement, and signal transduction pathways. These are just two examples but, as one might expect, not all topics have been developed into animations, and those that are freely available may not meet one's specific needs or teaching philosophy.

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In developing animations for any subject, it is important to understand what pedagogical attributes are most effective. It is well documented that narrated animations are more effective than those that lack narration (Mayer and Anderson, 1992; Sweller, 1994; Lowe, 2003). Furthermore, animations with concurrent verbal narration are more beneficial to the learner than visual narration (Mayer and Anderson, 1992). Mayer (2003) has provided evidence that students learn more effectively when words and pictures are combined ("multimedia effect") than from words alone and when printed words are placed adjacent to corresponding pictures ("spatial contiguity effect"). These results are consistent with the cognitive load theory, which is based on the concept that there is a limited amount of working memory, and by using both visual and auditory channels, working memory is increased (Mayer and Anderson, 1992; Sweller, 1994; Mayer *et al.*, 2001). Student depth of learning (comprehension) is enhanced by conversational style narrative ("personalization effect") and by the absence of extraneous content ("coherence effect"). There is a body of evidence that suggests that students do not perform better with animations when the animations contain more information than is appropriate (Tversky and Morrison, 2002). In short, the material provided to students must be appropriate to the topic at hand and to their educational status. The "apprehension

principle" states that in order for a learner to gain a proper understanding of the material, the content must be easily and accurately perceived and understood. Animations that move too quickly or that contain excessive extraneous detail or realism may overwhelm the learner, leading to little comprehension (Tversky and Morrison, 2002). There are other issues to consider in presenting an animation. Interactivity should be considered because even minimal interactivity (e.g., ability to pause, rewind, fast-forward) enhances the learning value of animations (Tversky and Morrison, 2002).

The perceived complexity of developing an animation can be a deterrent for most instructors. Heyden (2004) states that making animations and multimedia is "not a simple job" but is a "time-consuming and often frustrating" process. Here we show that this need not be the case. In fact developing one's own animations can be a relatively easy process; the issue is one of goals and complexity. My goal was to develop a method that any teacher or student could use to make animations that effectively convey dynamic events in a clear and meaningful way. Using the extensive data provided by others, as summarized above, I have developed animations that are focused (i.e., keep to a specific topic), include "conversational" narration coincident with occurring events, include appropriate terms as written text or labels adjacent to the event or structure under consideration, include narration of the labels as they appear (to reinforce learning and how words/terms are said), and finally, include a modicum of interactivity in the ability of students to rewind and review portions of the animation as they see fit. Here I show how these basic "rules" were applied to the development of an animation "Calcium and the Dual Signalling Pathway." Different sets of students then were given the opportunity to evaluate this animation or an equivalent set of still graphics with text and then asked to fill out a questionnaire to provide data on the educational value of the material they had viewed. Students were also asked for their opinions on the perceived value of graphics versus animations as teaching tools.

MATERIALS AND METHODS

Programs

PowerPoint 2003 (Microsoft Office Standard Edition 2003 for Students and Teachers, Redmond, WA) was used to generate the animations. Camtasia Studio 2.1.1 (TechSmith, Okemos, MI) was used to capture the animation and convert it to appropriate movie formats. Camtasia Studio has other screen capture attributes but only works with PowerPoint 2003 or higher. A 3-mo trial version of Camtasia Studio is available online at www.techsmith.com. A full version for educational use costs US$149. In addition, this product has multiple other uses as detailed on their Web site.

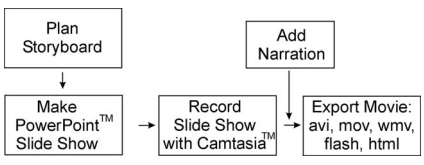

Figure 1. Basic sequence of events in planning and preparing an animation using PowerPoint in conjunction with Camtasia Studio.

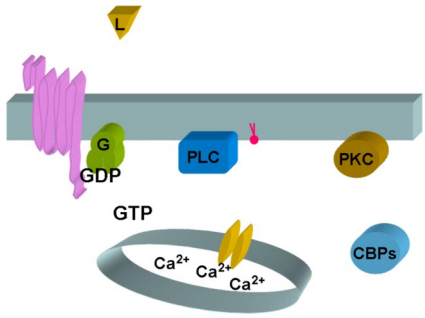

Figure 2. The starting slide or "cel" for the PowerPoint/Camtasia animation "Calcium and the Dual Signalling Pathway." Each of the components contained in sequence for the animation is drawn in its relative position. Multiple copies of the slide were made allowing the manipulation of each component and the addition of labels as needed.

Producing the Animation in PowerPoint

A flow chart for the production of the animation is shown in Figure 1. An animation is simply a collection of still images called "cels" that when viewed in rapid succession gives the impression of movement. In PowerPoint, each slide may be considered as a cel, but in addition some animations or movements can occur within each slide. First, as with any animation, you need to plan your sequence of events in a storyboard. For my animation "Calcium and the Dual Signalling Pathway,"[1] I used a very short storyboard based on models of this process (e.g., Berridge *et al.*, 2000). The author has extensive experience in the field of signal transduction, especially on calcium signaling (O'Day, 1990, 2006; O'Day and Myre, 2004). For the storyboard, I simply drew the complete pathway and made a note of the sequence of events and what I wanted to highlight during the animation. I also wrote a narrative covering the sequence to ensure I covered all relevant points.

In PowerPoint, I started the animation by drawing the full sequence of signaling components and their relative positions on a single slide (Figure 2). Components were given different shapes using the Autoshapes function plus simple circles, squares, and line drawings. These were then given depth by using the 3D depth Toolbox option. Text (names and acronyms) was inserted for each component. I added a simple background and made multiple copies of the slide (Insert → New Slide → Format Background to plain slide → Paste slide content). Sometimes when the contents of one slide are copied to a new slide, they shift in position slightly. If this occurs you should group (highlight items → Draw →Group) all of the items and then copy and paste them before ungrouping them on the new slide. You should save your PowerPoint slides as a new file after you complete any major changes so you have the original to go back to if you make any mistakes.

It is easy to add more copies of slides and delete the extras as you work through the animation. To start the animation sequence, I added a labeled box ("Hormone") with an arrow to indicate the hormone. I used shadow on the font to highlight it and filled in the box so there was no background show-through (a personal choice). I made a copy of the slide including the label and arrow, copied it as the next slide (Insert →New Slide →Format Background to plain slide → Paste), moved the label to indicate the receptor, and changed the text to "Receptor." A new slide was made for each

[1] In Canada, we spell some words in the British style (e.g., signalling with two "l's") as opposed to the American spelling. Also, I have used the older, classic term "Dual Signalling Pathway" because it reflects the duality of this event. See *Discussion* for more information on this topic.

component to be labeled with the arrows/labels moved and names changed as required. This can also be done in other ways by using Slide Show transitions, but if a mistake is made, you have to reprogram each label to appear in the right place at the right time. Making cels as slides allows you to move them around and edit each without encountering problems other than using more computer memory during the PowerPoint stage. A simple click of the mouse button in a slide show for this example made the "Hormone" label and arrow appear and indicate the triangular "hormone." Another click to the next slide makes it appear as if the hormone label disappears and the "Receptor" label and arrow appear.

After all of the components of the signaling pathway had been sequentially identified, it was time to start animating the components. The signaling event begins with hormone binding to the membrane receptor to activate it, followed by hormone-receptor binding to the G protein. To make the hormone move into the receptor, I copied the hormone triangle and put it over the receptor. I then used a motion path (Slide show → Custom Animation → Custom Path → draw path) to make the triangle hormone move from its original place to the receptor. I then copied the hormone adjacent to the receptor to the next slide and deleted it from the current slide, so that a mouse click first moved the hormone to the receptor. Then changing to the next slide shows the hormone localized at the receptor, initiating subsequent events. This same basic "Custom Animation" approach was used for all subsequent component movements within a slide with some minor changes. For example, because the inactive G protein has three subunits plus GDP, I grouped them together (highlight them together and then use Draw → Group) so they would move as a group; then I used the Custom Animation path sequence to move the heterotrimeric G protein to the receptor. At the receptor, the complex was ungrouped to allow text editing of GDP to GTP in the G protein and GTP to GDP in the cytoplasm to simulate the exchange. After this the alpha subunit-GTP and beta/gamma subunits were each separately grouped together. The Custom Animation path sequence was then used to move the alpha subunit-GTP to phospholipase C (PLC). The beta/gamma subunits were physically moved away from the receptor over the next few slides to suggest their separation (see *Discussion* regarding G protein models). The conformational change and activation of PLC by the alpha subunit–GTP interaction was indicated by a change in the color (blue to green) and shape (smooth rectangle to multipointed star) of the PLC enzyme. The splitting of the phosphoinositol-4,5-bisphosphate into 1,4,5-trisphosphate (IP3) and diacylglycerol (DAG) simply involved two sequential slides with arrows showing this separation. The Custom Animation path sequence approach was used to move the IP3 molecule into the cytoplasm to bind to and activate the IP3 Receptor (IP3R) channel. The IP3R channel was drawn as two components (gold) over a 3D circle (endoplasmic reticulum) within which calcium ions (text boxes) were placed. To simulate opening, a white circle was inserted behind the IP3R channel, and the two gold components were moved apart manually in the next slide. The Custom Animation path was used to move the calcium ions individually into the cytoplasm and to associate them with the calcium-binding proteins (CBPs) and, along with DAG, protein kinase C (PKC). As with PLC the activation of the CBPs and PKC was shown by a shape and color change.

Before the animation was captured, I went through the sequence and added, moved, or removed slides for continuity and smoothness. Rather than adjust the timing so the slide show ran on its own, I decided to do it manually using mouse clicks to fit with the narration. The narration can be done directly into the presentation or added during the final production using Camtasia. For personal reasons, I chose to record the sound on a high-quality recorder rather than directly into the computer but with new sound cards that are available, this is not necessary.

Movie Production: Camtasia Studio

Once you install the Camtasia Studio package, a record button is automatically inserted into PowerPoint. A simple click of the red "Record" button automatically starts the recording process. The recording will automatically terminate at the end of the presentation. A record audio button is also included adjacent to the Record button. Once the animation is captured, there are many options available within Camtasia Studio. For this work, I ignored all the options and simply used the program to insert the narration that I recorded separately. The full content of the narration is shown in Figure 3. If you record your narration as you go through your PowerPoint animation, you will also be able to insert music or another audio track (e.g., sounds) later to "punch up" your animation if desired. The value of such background music in educational animations is not clear. After adding the narrative, I then used the program to convert my PowerPoint into various formats (avi, mov, wmv, and flash, which were also variously embedded in html). Each of these different formats has its use. Each also uses different amounts of memory, and the animation appears slightly different in each format. You can also control most of these elements by clicking various options when you are asked before the final conversion of your animation. Because they are self-explanatory, I won't detail them here.

Once you capture your animation with Camtasia Studio, you can view it. If you are not satisfied with any part it is easy to go back to your original PowerPoint slides and rectify the problem. For example, if stages of the animation do not progress as smoothly as desired, it is easy to duplicate and insert a slide in the area and make the transition go more smoothly. In my first draft of this animation, I had a plain white background, but by adding a textured light blue background, the animation was much more visually appealing.

Producing the Static Graphic

The figures used in the evaluation were slides taken directly from the PowerPoint presentation and are exactly the same as those used to make the movie, with some minor exceptions (Figure 4). Some of the labels were moved to new positions, and in a few cases the text from several slides was combined. This was done to avoid overlap of the text boxes and to enhance the clarity of the figures. In the end

Calcium and the Dual Signaling Pathway
Narrative

Calcium-mediated signal transduction is essential to the functioning and survival of all cells. A number of proteins including receptors, enzymes and ion channels are involved in the process. At the start of the signaling process a hormone such as vasopressin has not bound to its specific receptor. At this time, the heterotrimeric G protein that mediates the signaling is inactive since it is bound to guanosine diphosphate or GDP, while guanosine trisphosphate or GTP waits in the cytoplasm.

Many other downstream components within the cell are also inactive, these include
-Phospholipase C
-Protein Kinase C
-Various calcium binding proteins

As well calcium ions are sequestered within the endoplasmic reticulum. The ions are kept from entering the cytoplasm because the IP3 receptor-linked ion channels are closed. A phospholipid called phosphatidyl inositol 4,5 bisphosphate or simply PIP2 resides within the lipid bilayer of the cell membrane.

The signaling process begins when the hormone binds to its receptor. This in turn leads to the binding of the inactive G-protein to the hormone-receptor complex. This binding leads to the exchange of GDP for GTP, leading to the activation of the G protein. The activated G protein can now bind to its target enzyme phospholipase C or PLC in turn causing its activation. The activated enzyme then enzymatically digests PIP2 into inositol 1,4,5 trisphosphate or IP3 and diacylglycerol or DAG.

The IP3 is released into the cytoplasm where it will bind to the IP3 receptor that is present in the endoplasmic reticulum. The binding of the IP3 to its receptor leads to the opening of the ion channel which will allow calcium ions to escape into the cytoplasm. Now free in the cytoplasm the calcium ions can bind to and activate the diversity of calcium binding proteins that exist and that oversee various cellular functions.

The calcium ions can also work with diacylglycerol to activate certain isoforms of protein kinase C
PKC is linked to many critical normal events as well as to cancer; its activation allows it to phosphorylate a number of target proteins involved in these events. When hormone stimulation stops, the system reverts to the resting state ready for the next round of hormone-receptor binding.

Figure 3. The complete narrative for the "Calcium and the Dual Signalling Pathway" animation. This narrative was read for the animation and included as text with the static graphic. The orally narrated animation (http://www.utm.utoronto.ca/~w3bio315/restricted/anim.htm) and six-paneled graphic (http://www.utm.utoronto.ca/~w3bio315/restricted/pic.htm) with the narration as text are available online.

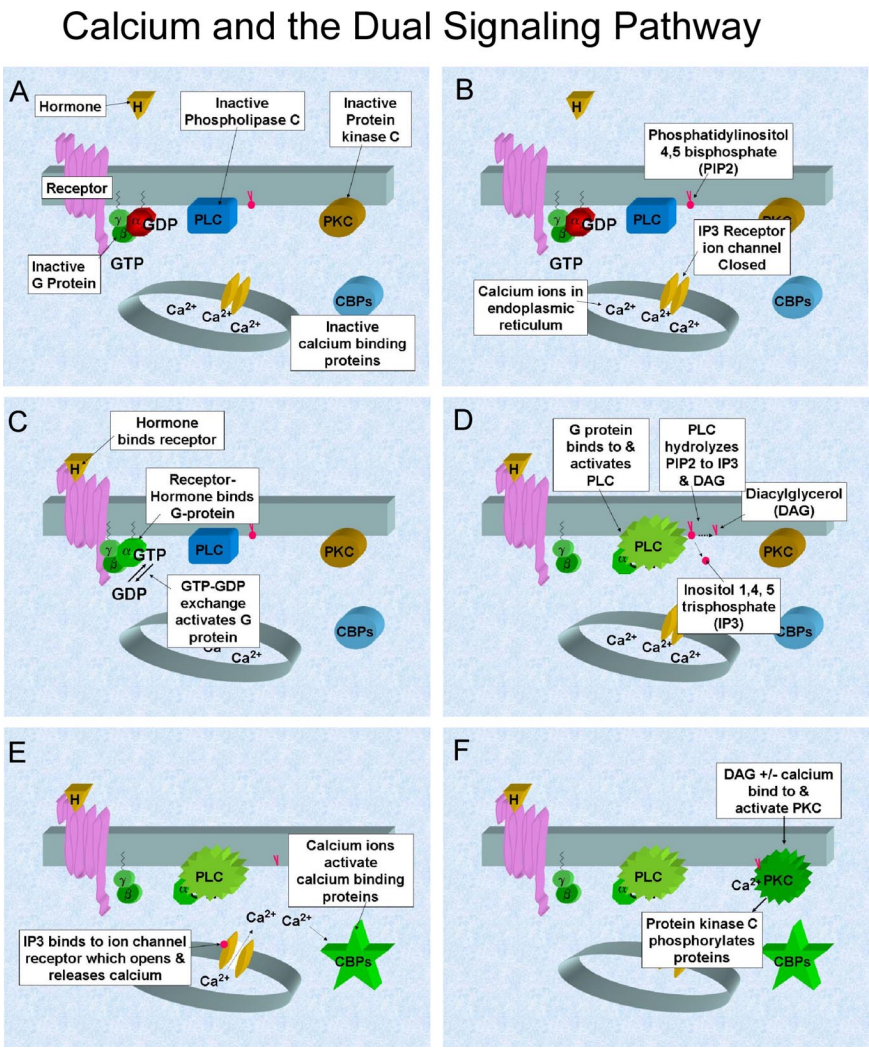

Figure 4. The complete figure for the "Calcium and the Dual Signalling Pathway" graphic. This figure also shows the events in sequential cels from the animation.

it was decided that six "slides" could be used to effectively convey the material. This number was chosen because it allowed for clarity and also kept the number of figures to a number that students could review multiple times in the time allotted. It also reflected what would commonly be presented in an equivalent textbook figure. Finally, in one slide the color of the arrows showing the hydrolysis of PIP2 to IP3 and DAG were changed to match the color of the molecules to avoid confusion with the arrows associated with the text box labels. Once the slides were recomposed in PowerPoint, each one was exported as a jpg image, and the set of six was composed into the final figure using CorelDraw 7.0 (Corel Systems, Ottawa, Ontario, Canada).

Student Evaluation of the Animation and Graphic

The animation (http://www.utm.utoronto.ca/~w3bio315/restricted/anim.htm) and six-paneled graphic with the narration as text (http://www.utm.utoronto.ca/~w3bio315/restricted/pic.htm) are available online. An equivalent educational background for each group was assumed because the students evaluating the material were all from the same junior (third-year) course at the same institution and all had met the same prerequisites to enroll in the course. During tutorials, students were randomly allocated to defined groups, directed to the URL of one or the other of these previously hidden Web sites by their teaching assistant, and then allowed to view the specific site as detailed in Table 1. The viewing of the animation and graphic Web sites as well as the completion of the evaluations were carried out under the supervision of two Ph.D. student teaching assistants without the participation of the author. The questionnaire shown in Figure 5 was handed out to the students after they had completed the exercise given to their group. The questionnaire consisted of some basic instructions plus four parts for the students to complete. A series of introductory questions (Part I. Introduction) was included to document what each student did and whether they felt they had enough time to review the material.

Table 1. The four experimental groups (with group sizes in parentheses) used in the evaluation

Group	Treatment
A (n = 21)	Graphic viewed 1–2 times maximum
B (n = 16)	Graphic viewed 3 or more times over 15 min
C (n = 16)	Animation viewed 1–2 times maximum
D (n = 33)	Animation viewed 3 or more times over 15 min

Advanced Cell Biology (BIO315HF)
Professor Danton H. O'Day

Animation versus Graphics Evaluation

Instructions. Depending on your group you will have been given the URL to a web page that displays either an animation or a static graphic of "Calcium and the Dual Signalling Pathway". Depending upon the group to which you have been assigned, you will have been allowed to study the material in a specific way before being provided with this questionnaire. Now, we would like you to answer the following questions to the best of your ability.

Part I. Introduction

1. Which did you view?
☐ Animation
☐ Figure with text

2. How many times were you able to get through the material provided?
☐ Once
☐ Twice
☐ Three times
☐ More than three times

3. Do you feel that you were given enough time to view this material before being asked to complete this questionnaire?
☐ No
☐ Yes

Part II. Specific Questions. Please indicate the correct answer...

1. Before hormone binding occurs which of the following is not true?
a. Phospholipase C is inactive
b. Protein Kinase C is inactive
c. The receptor is bound to a G protein
d. Diacylglycerol is localized in the cell membrane
e. Calcium binding proteins are not yet activated

2. Which of the following statements is not true about the dual signalling pathway.
a. It mediates divergent downstream signalling events
b. It involves calcium-mediated signalling events
c. It involves phospholipid-mediated signalling events
d. It involves several protein dephosphorylations
e. It involves two or more enzymes

3. The depicted G protein consists of how many subunits?
a. Two different subunits
b. Three identical subunits
c. Three different subunits
d. Four different subunits
e. Four identical subunits

4. In response to hormone binding, the receptor does not...
a. Move into the cytoplasm
b. Become activated
c. Undergo a conformational change
d. Initiate intracellular signalling events
e. Remain within the membrane

5. The G protein becomes active when...
a. Guanosine diphosphate displaces guanosine trisphosphate
b. Adenosine trisphosphate displaces guanosine trisphosphate
c. Guanosine trisphosphate displaces adenosine trisphosphate
d. Adenosine trisphosphate displaces guanosine diphosphate
e. Guanosine trisphosphate displaces guanosine diphosphate

6. Activated Phospholipase C...
a. Hydrolyzes inositol 4,5 bisphosphate into inositol 1,4,5 trisphosphate and diacylglycerol
b. Hydrolyzes inositol bisphosphate into inositol 4,5 trisphosphate and diacylglycerol
c. Hydrolyzes inositol 4,5 bisphosphate into PIP2 and DAG
d. Hydrolyzes inositol 1,4,5 trisphosphate into inositol 4,5 bisphosphate and diacylglycerol
e. Hydrolyzes PI3 into PIP2 and DAG

7. The intracellular protein that binds to inositol 1,4,5 trisphosphate...
a. Is also a sodium ion channel
b. Is found in the endoplasmic reticulum
c. Allows calcium efflux into the extracellular space
d. Is activated by G proteins
e. Opens in response to PIP2 and/or DAG activation

8. Inositol 1,4,5 trisphosphate...
a. Binds to a receptor to release calcium
b. Binds to PKC to activate it
c. Binds to downstream enzymes
d. Binds to mitochondria to allow calcium influx
e. Binds to Inositol 1,4,5 trisphosphate binding proteins in the cytoplasm

9. Which of the following is not true about protein kinase C?
a. It exists as different isoforms
b. It dephosphorylates specific downstream proteins
c. It can be activated by DAG and/or calcium ions
d. It has been linked to various forms of cancer
e. It adds phosphate groups to downstream proteins

10. Which of the following is not true about the dual signalling pathway?
a. It involves enzymes, phospholipids and proteins
b. It depicts a series of protein-protein interactions over time
c. It involves several proteins undergoing various conformational changes
d. It involves enzymes, ions, binding proteins and phospholipids
e. It involves enzymes, phospholipids, nucleic acids, and binding proteins

Part III. We want your Opinion.

1. Did you find the material provided a useful learning experience?
☐ Yes
☐ No
☐ Don't have an opinion

2. If you answered No to the above, please explain why you feel this way?

3. Did you make a serious effort to learn the material?
☐ Yes
☐ No
☐ Don't have an opinion

Part IV. Comparison Questions

In this section we want you to tell us which works best for you as a student: animations or static graphics. After you have viewed the alternative animation or graphic please answer the following questions.

1. Which did you view second?
☐ Animation
☐ Figure with text

2. Having viewed both items, which would you prefer to use in studying for tests and exams?
☐ Animation
☐ Figure with text

3. Do you think you would spend more time studying if you were given more animations rather than static pictures?
☐ Yes
☐ No
☐ Don't have an opinion

4. Please feel free to provide any written comments you would like to make about any of your above responses and any of the material covered today.

Figure 5. The complete three-page form used for evaluation of the pedagogical value of the animation and for acquiring students' opinions.

This was followed by 10 specific questions about the content of the material they reviewed (Part II. Specific Questions). A third part (Part III. We want your opinion) was included to get input into the perceived value of the exercise and also to include a control question (Part III. 3). The final part (Part IV. Comparison Questions) was to be answered after the students were given a chance to review the alternative material (i.e., students who first viewed the graphic were asked to then view the animation and vice versa). In addition to generating information about the value of the provided material, this section also allowed us to assess whether the questionnaire was completed with care. For example, if a student viewed the animation first and in Part IV checked the box with Animation (Part IV. 1) or did not check any box, this would indicate they were casual about the exercise. These evaluation forms were removed before analysis of the data as detailed in the *Results*. For data analyses, a one-way analysis of variance (ANOVA) with a Barlett's test for equal variances was performed using GraphPad Prism version 4.03 for Windows (GraphPad Software, San Diego, CA).

RESULTS

Completion of Evaluation Forms

Students were asked to view the graphic and text (group A) or the animation (group C) a maximum of two times before filling out the questionnaire. Other sets of students were allowed 15 min to review the graphic and text (group B) or the animation (group D), providing them with enough time to review the material a minimum of three times. A total of 103 students voluntarily completed the anonymous evaluation forms in three different tutorial sections. Of these, 17 were not used because they were incomplete, the student did not take the process seriously (i.e., responded "No" or "No Opinion" on Q. III.3), or there were other anomalies (e.g., more than one box checked). Those questionnaires were removed before any further data analysis. In the end, 86 evaluation forms (83.5% of those completed) were used. These remaining evaluation forms comprised the complete data for the four experimental situations (Table 1).

Statistical Analysis

A comparison of the groups' responses to the 10 questions in Part II was carried out (Figure 6). Students who viewed the static graphics once or twice had a mean score of 69.4% (±3.9 SE). Viewing the graphic three or more times resulted in a slight grade increase (71.3 ± 3.4% SE) over viewing it once or twice. A single viewing of the animation led to a mean score of 57.6% (±2.1 SE). However, viewing the animation three or more times resulted in a mean score of 84.4% (±4.1 SE). A one-way ANOVA revealed that the results for group D were significantly ($p < 0.05$) different from groups A, B, and C. It also revealed that group C was significantly ($p < 0.05$) different from groups A and B. Thus, viewing the animation three times or more over a 3-min period was more likely to generate a high score than an equivalent amount of perusal of a static graphic. It is also apparent that viewing the animation once or twice is less instructional than an equivalent viewing of a graphic with text.

This was followed by simple comparison of the success each group had on specific questions (Table 2). For this comparison, the results of group A student responses to each individual question were compared and the four most poorly answered questions then were compared with the results from the other groups. For all questions, group D scored much higher than all of the other groups. For example, on question 2, the most poorly answered question in group A (37.5% correct answers), 87.5% students in group D got the correct answer. However, groups A and B scored higher than group C. This was most evident in question 7 where group C students had fewer correct (23.8%) than either group A (43.8%) or group B (45.5%). These results further emphasize the two main points above: multiple viewings of the animation led to more understanding/retention than repeated viewing of static graphics, but even limited time for viewing static graphics is more rewarding that insufficient viewing of an animation.

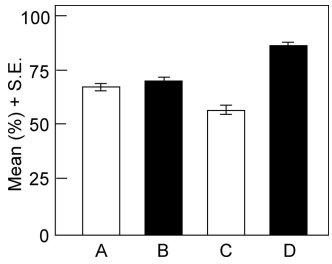

Figure 6. A bar graph showing the results of the four groups on questions based on viewing the animation or static graphic. Error bars, mean ± SE. As detailed in *Results,* ANOVA revealed that the results for group D were significantly ($p < 0.05$) different from groups A, B, and C, whereas group C was significantly ($p < 0.05$) different from groups A and B.

Table 2. A comparison of the results of each group on the most difficult questions in the evaluation

Question no.	Group result (%)			
	A	B	C	D
2	37.5	51.5	42.9	87.5
6	50.0	66.7	19.0	75.0
7	43.8	45.5	23.8	62.6
9	56.3	33.3	42.8	68.8

Satisfaction of Student Groups

The different groups expressed different levels of satisfaction about the amount of time provided before they had to complete the evaluation form (Part I. 3). Group A, which viewed the graphic once or twice, was the least satisfied with 43.8% believing that they did not have enough time to view the material. Group C (animation 1–2 times) was the next least satisfied with 23.8% believing that not enough time was provided. On the other hand, when given the chance to review the material multiple times, students in group B (90% Yes) and D (94% Yes) were satisfied with the time allocated for reviewing the material.

Preference of Student Groups

Although the majority of students (77.1%) indicated that they preferred using an animation over a static graphic with text for studying for tests or exams, there was increased preference for the animations after extended viewing. Those who viewed the graphic first showed a preference (Group A, 68.8% and Group B, 73.3%) similar to that of those who only viewed the animation once or twice (Group C, 71.4%). On the other hand, viewing the animation for three or more times led to an increased preference (Group D, 94.1%) for using animations over graphics for studying. However, these results should be considered in the context of specific comments made by students, which suggest that most students find that static graphics and animations each have specific roles in the learning process.

Comments Made by Students

". . . the pictures are great for getting the terms down and having something on paper to study when no computer is

available. The animations really show the bigger picture . . . . I would prefer to use both in combination to study for tests and exams."

"I prefer the figure with text because I can go at my own pace. . . . I also learn better by reading something for myself rather than it just being told to me."

Regarding graphics: "[I] tend to notice names of components more," and animation: "[I] get an overall picture of what is happening."

Animations are much more effective for "dynamic events or a series of occurrences."

"[The] animation was much clearer and easier to follow than the series of static pictures."

"Relying on the computer for animations before tests and exams can be risky . . . , [especially] . . . if you don't have last minute access."

"I learn very slowly. . . . [A] combination of both would be great!"

"Animations are preferred if I have to pick one, but I feel the figures with text are also helpful in conjunction with the animation."

"Easier to review something specific . . ." with static graphics.

"Personally, I understood the process better after viewing the animation."

The G protein cycle ". . . was very clear in the animation compared with the graphic. . . ."

"Together the animation with narration was a great learning tool."

"I prefer animations to be downloadable rather than part of a Web site."

"You don't always have access to a computer."

"I'm a visual learner, so seeing how the sequence of events . . . unfold in a video helps me to learn better. It is also much better because the labels are not everywhere which can be confusing."

". . . after watching the animation, I felt like I will never forget these study materials."

". . . because animations can do two or more things at the same time, it lets the students pay more attention to these things."

"I like animations because they tell us the names separately . . . and the pronunciation is provided."

In summary, many students expressed the opinion in different ways that graphics are more useful than animations for making study notes because it is easier to find points with static text and pictures. Most students also indicated that each has its place and they would prefer to have access to both in the learning process.

DISCUSSION

This work has shown that pedagogically meaningful cell biology animations can be made using PowerPoint. In conjunction with a capture package such as Camtasia Studio, these animations can then be converted to any current viewing format for use in class or for use on the Web. The key to developing such effective animations requires the adherence to a few fundamental rules or principles developed by many others. The first principle is that the animation should be orally narrated, preferably with a conversational tone (Mayer and Anderson, 1992; Sweller, 1994; Lowe, 2003; Mayer, 2003). The second principle is that text boxes or labels should appear over appropriate structures as they are first mentioned and that the value of these labels is enhanced by hearing the text at the same time it appears (Mayer, 2003). The third principle is that the material should be stage-appropriate, not contain extraneous detail, and not be overwhelming to the viewer (Tversky and Morrison, 2002). The fourth principle is that an element of control (e.g., ability to stop, rewind, fast-forward) should be provided (Tversky and Morrison, 2002). Finally, one can use simple visual clues (e.g., changing colors/shapes to signal an event) to augment the learning process. I have used these principles to guide the development of the animation presented here. Because the animations include all of the major parameters associated with successful learning, they can be used by students with diverse learning abilities and backgrounds.

The question remains, does theory meet reality? To determine if the PowerPoint/Camtasia animation "Calcium and the Dual Signalling Pathway" had pedagogical value, students were asked to view either the animation itself for specific times or an equivalent graphic with text (Table 1). They were then asked questions about the content of the material viewed. The results of the evaluation completed after viewing the animation or graphic first for various times indicated that the animation can lead to better learning if sufficient time is given for viewing it. When students were allowed to view the 3-min animation three or more times over a 15-min period, their results on the 10 questions asked on the evaluation form were significantly higher than those for viewing the animation one or two times or viewing the static graphic for up to 15 min. However, when students were only able to view the animation once or twice, they were unable to answer as many questions correctly as students who had viewed the static graphic once or twice. In contrast, increased reviewing of the graphic did not lead to an increase in the grade obtained for the 10 questions. These results support earlier work that animations lead to increased student understanding and retention of cell biology information (McClean *et al.*, 2005).

Often, as educators we fail to poll our students about their wants and needs. For this reason I included a component that asked students for their opinions. The insights they provided were quite valuable. The majority of students stated that they preferred viewing an animation over a static graphic with some caveats. In preferring an animation, students my be inclined to spend more time reviewing material presented this way, which in turn would generate greater retention of the information. It should be kept in mind that although students preferred animations, they believed that static graphics and animations each have specific roles in the learning process. Of all the student comments listed in *Results*, there was one major, recurring point: animations allow students to understand the dynamics of a complex process, but graphics serve as a critical tool for studying the details of the component events, especially in preparing for tests and exams. Although this basic idea was expressed in a number of different ways by the majority of the students, not all agree. One student stated, "I find myself losing concentration with the animation." Although the data overall support the value of animations, such statements clearly reflect the

need to include a diversity of teaching modalities if we are to communicate effectively to all students.

There are many excellent animation programs in the marketplace. Heyden (2004) has reviewed the strengths and weaknesses of the most commonly used animation packages. Two comparatively expensive programs, Micromedia Flash Player (Adobe Photosystems, San Jose, CA) and Maya Unlimited (Great Eastern Technology, Woburn, MA), have been used to make cell biology animations, some of which are available free online (see articles for animation URLs: Stith, 2004; McClean *et al.,* 2005). Such programs are powerful and can open up the ability to develop true 3D animations. They also have other attributes (e.g., greater interactivity) that can assist in teaching and learning. My goal was not to try to compete with such excellent programs but to consider an old adage on "overkill" (e.g., using a cannon to kill a fly when a fly-swatter is sufficient). In some cases, those programs are much too powerful for basic animations like that presented here. As indicated by one article, "Flash has a steep learning curve, especially for complex animations (e.g., one minute of animation may require 10 h of work)" (Stith, 2004). In another, a team effort that generates animations using the professional animation package Maya Unlimited, it was determined that each short animation took 240 h to produce. Not only does it take a long time to learn the program, producing animations subsequently is a labor-intensive process. Most teachers already have a strong working knowledge of PowerPoint, precluding any significant "learning curve." Camtasia Studio is a direct, user-friendly, add-on to PowerPoint, allowing the user to simply click on a button and start their PowerPoint presentation/animation. With this program, the final conversion to a viewable movie format takes only minutes.

As detailed in *Materials and Methods,* a limited number of attributes of PowerPoint 2003 were used to generate the animation "Calcium and the Dual Signalling Pathway": copy/paste, format slide, insert background, basic drawing skills, 3D depth, and custom path animation. Clearly, this can be sufficient for use in teaching because in this study many students involuntarily commented on the high quality of this animation. There are many attributes of PowerPoint that were not used. Clearly, with these new components and commercially available components now available for PowerPoint, even more visually impressive animations might be produced without extensive training or experience. However, the key is to remember is what you are trying to communicate and not to confuse "bells and whistles" with pedagogical enhancement. Camtasia Studio is a useful add-on because it allows the export of PowerPoint animations in essentially all of the currently used media formats, either as stand-alone animations or incorporated into html documents for immediate use in a Web site. These animations also can be saved at varying resolutions, allowing the animations to be used during lecture or online for distance learning. There are many other attributes of Camtasia Studio that were not used in this work. Furthermore, a comparative analysis of other such capture programs was not attempted because it was beyond the scope of this work.

There are many other reasons why using the PowerPoint/Camtasia animation approach should be beneficial to cell biology instructors and their students. A major benefit is the ability to revise animations quickly and easily. For the animation presented here, the title could be changed to reflect the more current use of the term "phosphoinositide signaling pathway," and specific components could be changed to reflect a specific pathway. For example, the word hormone could be changed to a specific ligand (e.g., acetylcholine), its specific Galpha subunit could be specified (e.g., Gs), the specific PLC isoform could be indicated (e.g., PLCbeta), and so on. A slight variation in the narration would then make the pathway cell and/or ligand/hormone specific. Similarly as new evidence becomes available, the animation easily can be revised or updated. Recently it has become clear that the classic "dissociation model" of the heterotrimeric G protein does not fit all predictions for all signaling pathways. This has led to the development of the nondissociative or "clamshell model" for G protein function (Robishaw and Berlot, 2004). With the clamshell model, the G protein subunits when bound to GTP do not dissociate but instead remain attached to the receptor, undergoing a conformational change that opens up domains for subsequent protein–nucleotide and protein–protein interactions. This in turn leads to additional protein binding (e.g., formation of a Receptor-Gq-PLC complex). To change the "Calcium and the Dual Signalling Pathway" animation, the G protein–GTP complex would simply remain in association with the hormone-receptor complex, and PLC could be moved by motion path to bind to the complex.

In conclusion, the existing data would argue that animations that are well paced, stage-appropriate, focused, and narrated verbally with complementary visual text as appropriate can help students learn dynamic processes. We have taken these ideas plus the concept of complexity and stage-appropriate content into consideration in designing our animations and have evaluated by questionnaire their pedagogical value in an undergraduate biology class. The results support the widely accepted idea that there is value in using animations for teaching cell biology and other subjects. More importantly, by developing an easy-to-use and effective animation method by taking the PowerPoint/Camtasia animation approach, the door is open to the development of animations by both faculty and students. Because most teachers and students today know how to use PowerPoint, animations can be made and shared with others, who in turn could adapt them to their specific needs with minor changes to the presentation and narration. Such sharing could also be done to generate a team effort. Because of the simplicity of the system, students could do their own animation projects as part of a course to demonstrate a specific event or process. Using the PowerPoint/Camtasia animation approach, more instructors should be able to develop and test animations to generate more data on the strengths and weaknesses of using animations in teaching cell biology as well as other subjects. For example, in the data presented here the value of using animations in conjunction with lecturing was not addressed as it was by McLean *et al.* (2005). To our knowledge, no study has addressed the issue of the effect of animations on long-term retention of information. There are many other variables that remain to be tested and many more questions to be answered; the approach to animation presented here should provide a useful tool to assist cell biologists in testing those variables and answering those questions.

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REFERENCES

Berridge, M. J., Lipp, P., and Bootman, M. D. (2000). Signal transduction: the calcium entry pas de deux. Science *287*, 1604–1605.

Heyden, R. J. (2004). Approaches to cell biology: developing educational multimedia. Cell Biol. Educ. *3*, 93–98.

Lowe, R. K. (2003). Animation and learning: selective processing of information in dynamic graphics. Learning Instruction *13*, 157–176.

Mayer, R. E. (2003). The promise of multimedia learning: using the same instructional design methods across different media. Learning Instruction *13*, 125–139.

Mayer, R. E., and Anderson, R. B. (1992). The instructive animation: helping students build connections between words and pictures in multimedia learning. J. Educ. Psychol. *84*, 444–452.

Mayer, R. E., Heiser, J., and Lonn, S. (2001). Cognitive constraints on multimedia learning: when presenting more material results in less understanding. J. Educ. Psychol. *93*, 187–198.

McClean, P., Johnson, C., Rogers, R., Daniels, L., Reber, J., Slator, B. M., Terpstra, J., and White, A. (2005). Molecular and cellular biology animations: development and impact on student learning. Cell Biol. Educ. *4*, 169–179.

Nicholls, C., and Merkel, S. (1996). The effect of computer animation on students' understanding of microbiology. J. Res. Comput. Educ. *28*, 359–372.

O'Day, D. H., editor. (1990). Ca^{2+} as an Intracellular Messenger in Eucaryotic Microbes, Washington, DC: American Society for Microbiology Publications.

O'Day, D. H. (2006). Calmodulin-mediated signalling in *Dictyostelium discoideum*: CaMBOT isolation and characterization of the novel poly-domain protein nucleomorphin and other calmodulin binding proteins. In: Cellular Signaling: New Research, ed., F. Columbus, Hauppauge, NY: Nova Science Publishers.

O'Day, D. H., and Myre, M. A. (2004). Calmodulin binding domains in Alzheimer's disease proteins: extending the calcium hypothesis. Biochem. Biophys. Res. Commun. *320*, 1051–1054.

Pollock, E., Chandler, P., and Sweller, J. (2002). Assimilating complex information. Learning Instruction *12*, 61–86.

Robishaw, J. D., and Berlot, C. H. (2004). Translating G protein subunit diversity into functional specificity. Curr. Opin. Cell Biol. *16*, 206–209.

Sweller, J. (1994). Cognitive load theory, learning difficulty, and instructional design. Learning Instruction *4*, 295–312.

Stith, B. J. (2004). Use of animation in teaching cell biology. Cell Biol. Educ. *3*, 181–188.

Tversky, B., and Morrison, J. B. (2002). Animation: can it facilitate? Int. J. Human Comput. Stud. *57*, 247–262.