

Animations for Learning: Design Philosophy and Student Usage in Interactive Textbooks

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Abstract

Animations have been used in science and engineering to facilitate student learning of difficult concepts. For example, microwaves have been animated to help electrical engineering students visualize field behaviors, and electron flow in electrolyte solutions have been animated to address misconceptions in college chemistry. Much research has examined the effectiveness of animations and visualizations in engineering education. Further, many types of animations utilize various formats for conveying the dynamic concepts. Some formats utilize captions, some are continuous, some give student controls like pause and play speed, some use animations for only motion, and so on. We have developed an animation format philosophy over the last 7 years that has been applied to multiple engineering and math disciplines with wide-spread adoptions. Our animations are integrated into web-based interactive textbooks and been viewed 30 million times by over 500,000 students across 600 universities. The philosophy includes two general actions: Unveiling a complex concept, and visualizing a dynamic process. This paper describes that animation format philosophy, including pedagogical considerations made in designing animations, multiple examples, and reasons for implementing an animation.

1. Introduction

Animations have increasingly been incorporated into learning materials to help explain difficult or hard-to-visualize concepts. Video-based animations have long been used to teach science and liberal arts topics [1][2][3], but as computer use has increased in classrooms, computer-based animations have been introduced to supplement learning [4]. Within engineering education, computer-based animations have been used to help students visualize electric field behaviors [1], highlight examples of thermodynamic processes [5], and simulate traffic for transportation engineers [6].

Over the last 7 years, we have developed a computer-based animation format philosophy that has successfully been applied to multiple computing, engineering, and math disciplines. These animations have been integrated into over 25 web-based interactive textbooks used by over 500,000 students at 600 universities [7]. Our philosophy uses animations for two specific content purposes: to unveil a complex concept, and to visualize a dynamic process. This paper describes the pedagogical considerations made in the development of our computer-based animations, and presents examples from various engineering disciplines.

2. Our Animation Style

Previous research has defined an animation as a simulated motion picture that contains: (1) visual objects created artificially through drawing or simulation and (2) motion [8]. The visual objects can be 2D or 3D, and simplistic or realistic in appearance. The range of object motions can also vary from simple, like an object moving across the screen, to complicated, like a realistic display of a human face talking. Animations may also vary in the ways a user can interact with the visualization. Some computer animations allow for high interactivity with the visuals through clicking or dragging objects, with the animation responding to user actions [9]. Less interactive animations may only allow a user to stop, pause, or play a visual sequence, and some remove interaction altogether by only playing on a continuous loop.

We define an animation, in the context of our interactive textbooks, as a visualization that:

1. contains simplistic animation instructions, similar to features available in PowerPoint or Keynote presentations,
2. is self-contained and presented in captioned author-defined steps, rather than in a continuous infinite loop, to allow users to stop and play steps as needed.

Our animation instructions include move, opacity change (fade or appear), background color change, resize, and rotate. Each instruction supports a delay before executing, which may also be set to execute concurrently with the previous instruction. The background color change supports a set of 12 colors plus transparent; a benefit of pre-set colors is that the colors were pre-chosen to work well together and enable an author to quickly choose a color. The colors were chosen to contrast with each other since in teaching, color is used sparingly to call attention to group related items or to draw attention to an item. Our colors were also chosen with awareness of common red/green color blindness

The above-described simple animation format gives students more control over the pace of the presentation, which has been shown to help students better understand information [10]. As shown in Figure 1, an animation contains:

1. A title describing the animation at a high-level.
2. A back-to-start button, which allows users to jump to the initial state of the animation.
3. Numbered steps, which users may click to jump forward and backwards in the animation.
4. A play button for users to pause or play the animation.
5. A speed checkbox for users to control the speed of motion the animation plays
6. An area for the visualized objects that are animated.
7. An area for the caption describing the current step.

This format can be implemented in PowerPoint or Keynote; however, PowerPoint and Keynote allow users to step outside this format. To keep the format consistent, we developed our animation creator tool to only support that format. The benefits of such restrictions include: ensuring good practices are used when authoring, and saving an author time and simplifying maintenance by limiting choices.

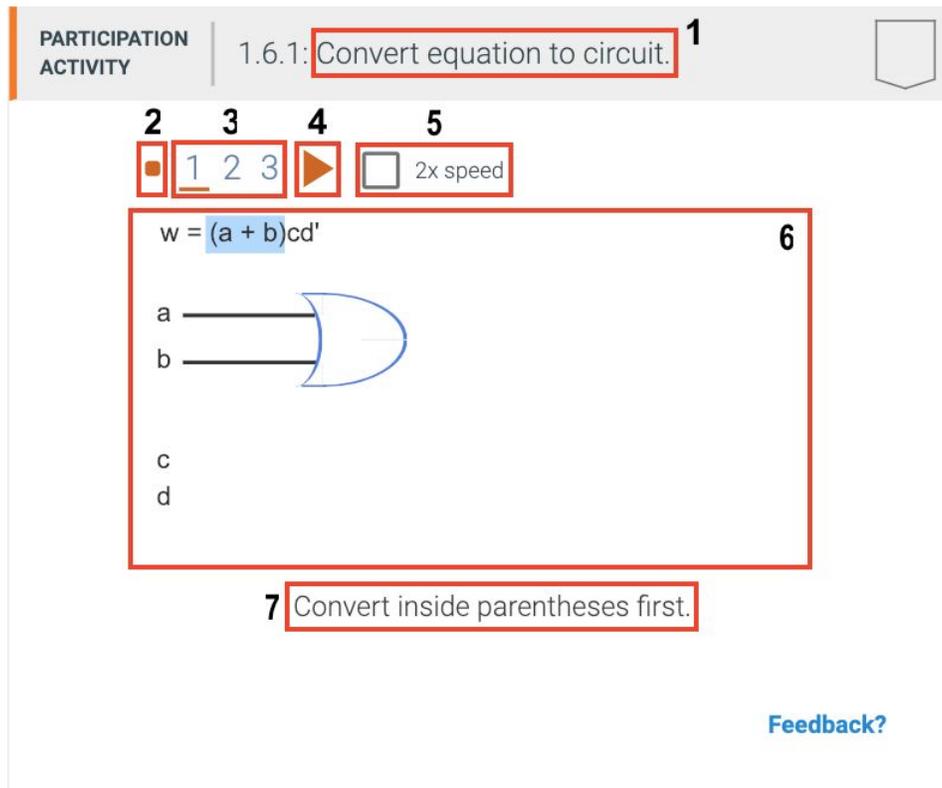


Figure 1. The components of an animation are numbered as follows: (1) title, (2) back to start button, (3) steps, (4) play button, (5) speed checkbox, (6) visualization area, and (7) caption. The orange boxes highlight those components and do not actually appear in an animation.

As shown in Figure 2(a), the initial state of the animation looks like a typical figure with all the objects visible. From the initial state, clicking the Start button plays the first step. Figure 2(b) shows the end of the first step, with the caption described the highlighted object. Highlighting key objects to associate with a caption is a typical technique to direct student's attention. Figure 2(c) shows the end of the animation (which is also the end of step 3). Note that the end of the animation looks exactly the same as the initial state. That is by design, so that a student (or instructor) who is reviewing the material can see the full "figure" at a glance.

From Figure 2(c), if step 1 is clicked, then the animation start playing from the beginning of step 1, which would end at Figure 2(b). Similarly, if step 2 or 3 is clicked. From Figure 2(b) or Figure

2(c), if the orange box (to the left of step 1) is clicked, then the animation will transition back to the initial state, shown in Figure 2(a).

Students may be assigned an animation as part of assigned reading. When the student has completely watched each step, the animation is marked as completed, as shown by the check mark in the top-right of Figure 2(c).

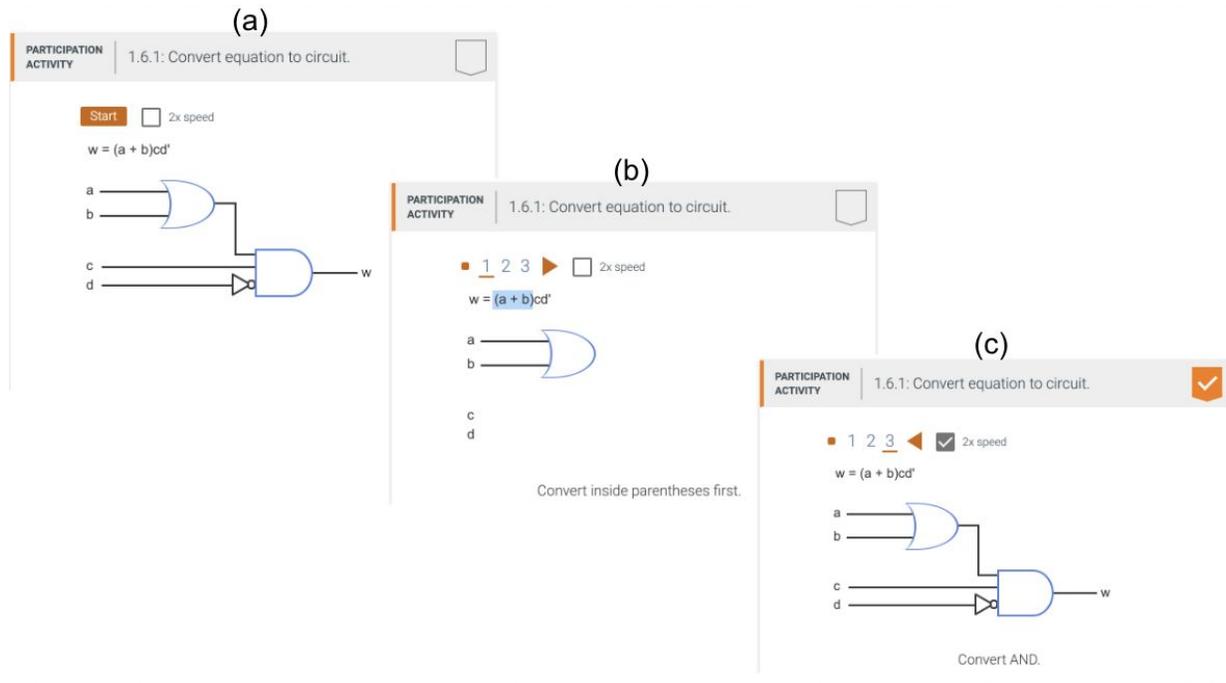


Figure 2. Screenshots of an animation from the (a) initial state shown before the student has started the animation, to the (b) end of the first step, and to the (c) end of the animation.

3. Determining When To Use Animations

In traditional textbooks, complex engineering processes have been explained using numerous static pictures accompanied by lengthy descriptions. Animations are used in our textbooks to meaningfully reduce such text. Our animations serve two distinct purposes: to unveil and relate items in a figure, and to teach dynamic processes. The following subsections provide examples of animations that unveil and animations for dynamic processes. For convenience to this paper's readers, these animations can be viewed via the YouTube links provided.

3.1 Animations for Unveiling Information

Complex static figures can be difficult for students to process. Students study the figure repeatedly while rereading the explanatory text, and they must remember this information as they try to relate various objects in the figure to build an understanding. Animations can be used to

foster understanding of complex systems by unveiling pieces of information bit by bit while explaining the relations between objects.

One such example is the use of an animation in our digital design textbook to explain how a finite state machine can be converted into a circuit. The animation consists of 7 steps, each unveiling a piece of information that results in understanding the whole diagram of the process. This animation can be viewed at <https://youtu.be/KD54tyXoXTs>. Figure 3 below shows the final diagram once all components have been unveiled.

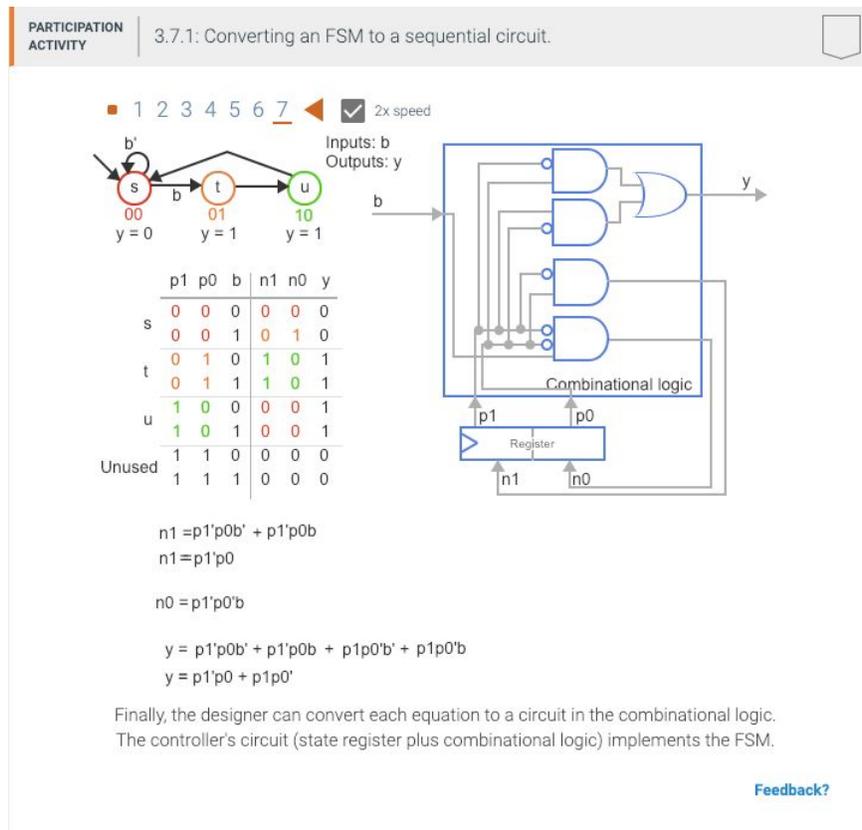


Figure 3. The final step in the animation ‘Converting an FSM to a sequential circuit,’ which unveils information relating how components of a finite state machine translate to a circuit.

In our view and based on numerous discussions with students and faculty, there is one common mistake described wherein an object disappears before the end of an animation. The reason this mistake is viewed as a problem is that the disappeared object is missing information for the rest of the animation, which may lead to confusion. This problem is not specific to our animations, of course; though, we now specifically discourage such disappearances.

3.2 Animations for Explaining Dynamic Processes

Many engineering concepts deal with dynamic processes, in which students must understand the changes occurring in a system. Explanations of dynamic processes in static text and images can be lengthy, and may not effectively capture the nuances of how changes occur. Because animations can use motion to demonstrate changes, animations are ideal for explaining dynamic processes.

We use an animation to analyze the process of a recursive function in our C++ programming text. Recursion occurs when a function, a piece of a program that carries out a task, calls itself and creates a new instance of the function. Recursion is a difficult concept for students to understand via static images, but an animation can clearly demonstrate each line of code and the resulting response. This animation can be viewed at <https://youtu.be/juBEnbY6GXU>. Figure 4 below shows the final instance of the recursive function.

The screenshot shows a web-based animation interface. At the top, it says 'PARTICIPATION ACTIVITY' and '11.2.1: A recursive function example.' Below this, there are navigation controls: a series of numbered buttons (1, 2, 3, 4) with the number 4 highlighted, a left-pointing arrow, and a '2x speed' checkbox. The main content area displays C++ code for a recursive function named `CountDown`. The code is as follows:

```
#include <iostream>
using namespace std;

void CountDown(int countInt) {
    if (countInt == 0) {
        cout << "GO!\n";
    }
    else {
        cout << countInt << endl;
        CountDown(countInt - 1);
    }
}

int main() {
    CountDown(2);
    return 0;
}
```

Below the code, a rounded rectangular box contains the output of the program:

```
2
1
Go!
```

At the bottom of the animation, there is a text box with the following text:

That last instance does not call `CountDown()` again, but instead returns.
As each instance returns, that copy is deleted.

In the bottom right corner, there is a 'Feedback?' link.

Figure 4. The animation ‘A recursive function example’ walks students through each call of the function `CountDown` and the resulting output.

4. Sample Animations from Engineering Topics

We've used animations for unveiling information and explaining dynamic processes across a variety of engineering topics. This section provides additional examples of such animations.

4.1 Electrical Engineering

An animation is used to describe the process of reading resistor values in our linear circuit analysis textbook. The animation describes the dynamic process of reading resistor band values from left to right to determine the total value of the resistor. Figure 5 shows the beginning, middle, and end of the animation.

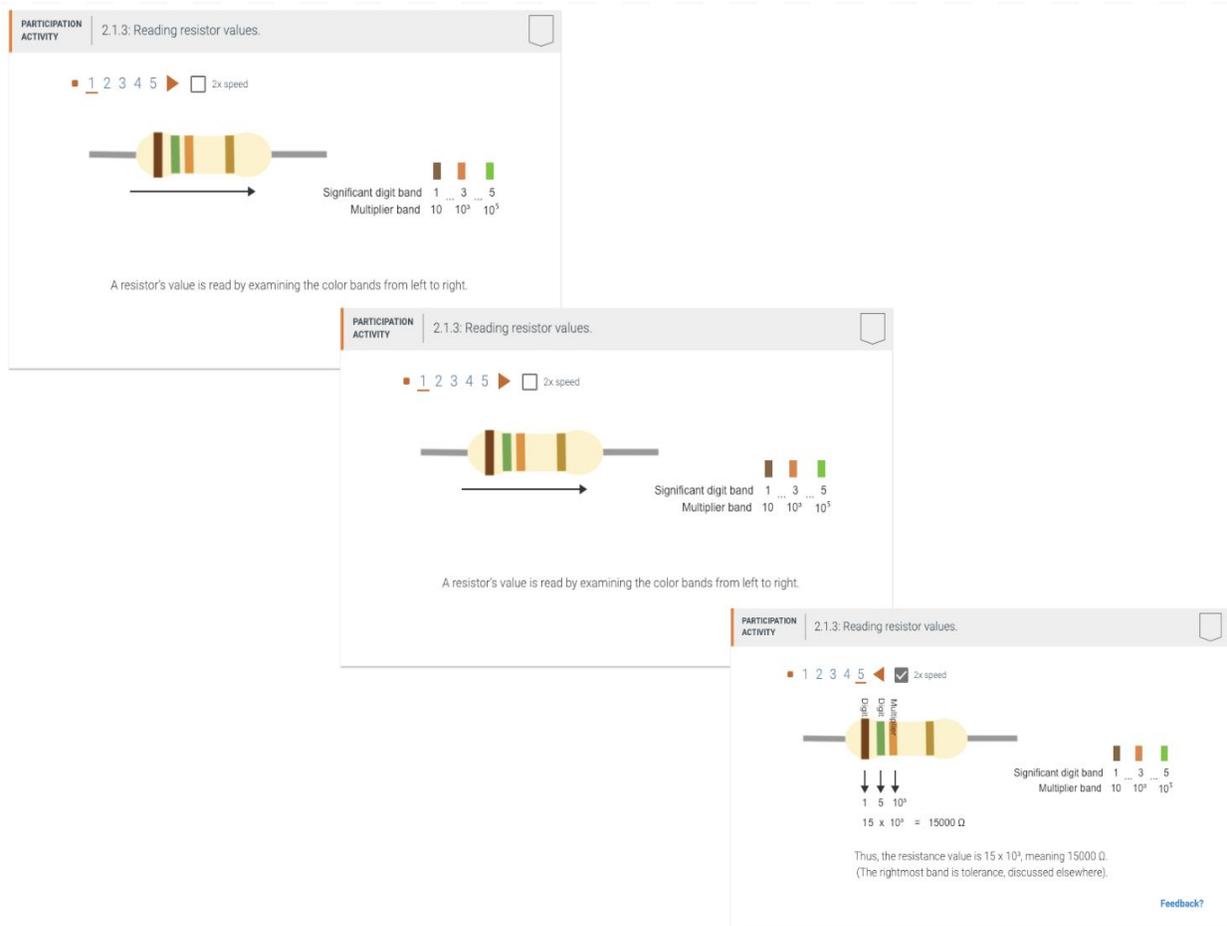


Figure 5. The animation 'Reading resistor values' describes the dynamic process of reading the color bands of a resistor to determine the resistor's value.

4.2 Chemical Engineering

Our material and energy balances textbook uses an animation to walk readers through the process of balancing a chemical reaction. Figure 6 shows how the animation progressively unveils information to obtain the final balanced equation.

The figure consists of three sequential screenshots of an animation titled "3.1.3. Balancing a chemical reaction." Each screenshot shows a progress bar with steps 1 through 6. Step 1 is highlighted in the first screenshot, step 3 in the second, and step 6 in the third.

Step 1: Shows the unbalanced chemical equation:
$$\text{N}_2 + \text{H}_2 \longrightarrow \text{NH}_3$$

Step 3: Shows the equation with variables:
$$1\text{N}_2 + x\text{H}_2 \longrightarrow y\text{NH}_3$$
 with "basis" under 1, "unknown" under x, and "unknown" under y. Below the equation, it says: "Ammonia is synthesized from reacting hydrogen with nitrogen." and "Add variables for the unknown stoichiometric coefficients."

Step 6: Shows the final balanced equation:
$$1\text{N}_2 + 3\text{H}_2 \longrightarrow 2\text{NH}_3$$
 with "basis" under 1, "unknown" under 3, and "unknown" under 2. Below the equation, it shows the atom balance calculations:
Nitrogen atom balance:
$$1 \text{ mol N}_2 \cdot \frac{2 \text{ atom N}}{1 \text{ mol N}_2} = y \text{ mol NH}_3 \cdot \frac{1 \text{ atom N}}{1 \text{ mol NH}_3}$$
$$2 = y$$

Hydrogen atom balance:
$$x \text{ mol H}_2 \cdot \frac{2 \text{ atom H}}{1 \text{ mol H}_2} = y \text{ mol NH}_3 \cdot \frac{3 \text{ atom H}}{1 \text{ mol NH}_3}$$
$$2 \cdot x = 3 \cdot y$$
$$= 6$$
$$x = 3$$

At the bottom, it says: "The last steps are to solve the atom balances and to finish balancing the reaction." and a "Feedback?" link.

Figure 6. The animation ‘Balancing a chemical reaction’ unveils the steps of balancing a chemical reaction.

4.3 MATLAB Programming

An animation is used in our MATLAB programming textbook to explain logical indexing. The complete animation is shown below in Figure 7.

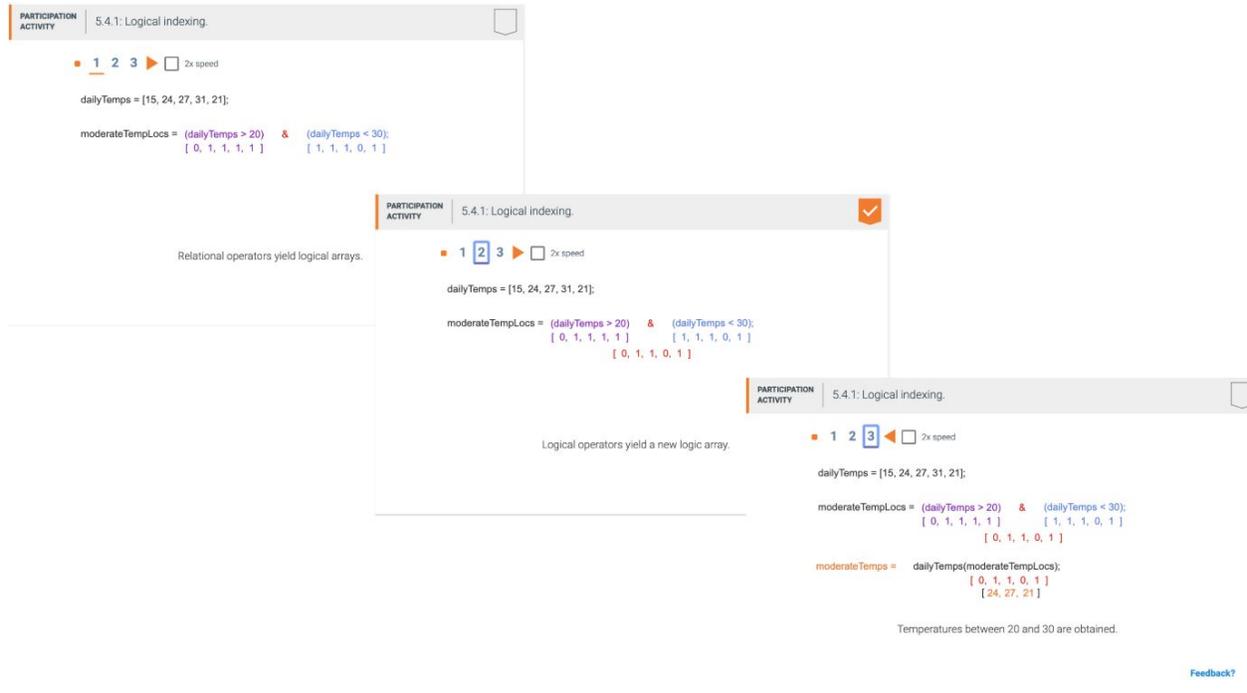


Figure 7. The animation ‘Logical indexing’ describes an example of using logical indexing to identify specific elements in an array containing temperature data.

5. Future work

This paper describes our animation philosophy, including examples from various engineering disciplines. Future work includes analyzing student usage of animations. Future work may also include evaluating the efficacy of our animation style to static approaches, as well as other animation styles. For example, comparing how well and efficiently students learn a set of concepts with our animation style vs other animation styles. Such measures of efficacy would be conducted in both a controlled setting, such as a single lesson with a pre-quiz and post-quiz, as well as cross-semester comparisons, such as a course switching to our animation style. Such cross-semester comparisons would include multiple courses.

6. Conclusion

Our animation format philosophy for incorporating animations in our engineering textbooks was described in this paper. Our animations contain simplistic movements similar to that of a KeyNote or PowerPoint presentation, and are displayed in steps to allow viewers control over the pace of the animation. The animations serve two purposes: to unveil and relate items in a figure, and to teach dynamic processes. This paper includes examples of how these types of animations were implemented in electrical engineering, chemical engineering, and MATLAB programming

books. Our animations have been implemented in over 25 web-based interactive textbooks to date and received over 30 million views, and as we continue to create more animations, we plan to conduct further research on their usage by readers.

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