ASEE 2022 ANNUAL CONFERENCE
Excellence Through Diversity
MINNEAPOLIS, MINNESOTA, JUNE 26TH-29TH, 2022 ASEE

Paper ID #36999

High-Quality Text Descriptions of Visual Elements in Online Interactive Versions of Traditional Print Mechanical Engineering Textbooks

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James Eakins

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Abstract

Even before the Covid-19 pandemic, there was an increased utilization of online course materials. Circumstances created by the pandemic increased the need for high quality online course content. These online course materials should comply with accessibility regulations and guidelines to provide an equal learning experience for all students. Although these guidelines describe broad requirements, specific standards for creating text descriptions of visual elements, both static and interactive, have yet to be created for mechanical engineering content. Research is lacking regarding accessibility of images and other visuals within online interactive mechanical engineering texts. Defining standards for how engineering visual elements like images and animations are textually described will provide a baseline to measure the effectiveness of visual elements for students who require assistive technology, such as screen readers.

The goal of this paper is to define accessibility standards developed for textually describing images, figures, graphs, animations, and other visual elements for a series of online interactive mechanical engineering textbooks (zyVersions) that have been adapted from traditional print textbooks. The group of content authors working on these zyVersions have written text descriptions (alt text) for the visual interactive content (animations) that have been added to the traditional textbook and in many cases have added to the text descriptions for figures including images, equations, and graphs that already appeared in the print text. The standards that have been used by this team of content authors include: (1) Writing text that balances precision with conciseness; (2) Structuring alt text to first capture important information, then incrementally filling in finer details; (3) Well-defined procedures for describing certain types of visual elements, such as phase diagrams and phase transformation plots in materials science and engineering, T-s, h-s, and P-v diagrams in thermodynamics, output response plots in control systems, as well as other common visual elements in mechanical engineering courses; and (4) Writing text for animated visual elements that describe in detail all dynamic processes and movements in the animation. This paper describes our guidelines in detail, and presents examples from three different zyVersions used in mechanical engineering courses. These standards can be modified for use across various engineering disciplines and will enable authors of online content to provide higher quality material that meets accessibility standards.

Introduction

The adoption of digital textbooks, or e-textbooks, by courses in higher education has grown since the turn of the 21st century. These textbooks can be in HTML, ePub, or PDF form. Advancements in technology have recently increased the development and implementation of multimedia features in e-textbooks as a new form of transmitting information [1]-[2].

Multimedia features enable interactivity with a meaningful pedagogical purpose that effectively improves student learning [3]-[4]. Yulda performed a systematic review of 20 articles with e-textbook adoptions and identified eight different types of features used: visual, graphic/design, system book roll, ESOTAG, augmented reality, real-time, animation, and digital based learning [5]. For example, [2] combines multiple features that include hyperlinks, detailed color drawings, demo videos, and animations in an interactive e-textbook for physics.

But, these features also introduce important issues, like accessibility and usability, that impose unnecessary obstacles to students with visual impairments. An exploratory study on the level of accessibility in engineering course webpages (e.g., Canvas) found eight inherent errors exist in digital learning platforms [6]. For example, color contrast in graphs and images without alternative text were two of the most common errors found in an Introduction to Engineering course. So, an e-textbook should not create additional barriers to the learning process that increase student struggle. Multimedia-enriched e-textbooks must meet Americans with Disabilities Association (ADA) requirements, including those established for web content by the Web Content Accessibility Guidelines (WCAG) [7]. By improving the tools used for accessibility, their level of quality and usability increases, which provides access to users with or without disabilities [8].

The present work aims to meet both ADA and WCAG guidelines at a minimum, while also establishing high-quality accessibility standards for mechanical engineering e-textbooks. Many e-textbooks rely on assistive technology (AT) tools, like screen readers, to play an audio reading of alternative text (i.e., alt text) description for images. Engineering e-textbooks typically involve complex images, plot figures, and animations. Sun et al. evaluated 140 STEM e-textbooks based on 15 SkillsCommons accessibility checkpoints, comparing HTML, ePub, and PDF formats using AT [9]. The authors found that for HTML formats with STEM content and AT, the passing rate decreases by a smaller margin compared to e-textbooks with no STEM content and non-AT. Thus, AT is more effective for students when an e-textbook has STEM content. The authors in [10] conducted a survey of 68 participants about their experience with using AT in web comics, which involve detailed images and artwork. Among ten types of given information, 57 of the 68 participants were most interested in being given a description of the scene followed by scripts of the speech bubbles.

Thus, the literature supports the need for high quality alt text for complex images, plot figures, and animations in mechanical engineering e-textbooks. The interactive mechanical engineering textbooks in the present paper incorporate learning questions with static images and animations, as in [11]-[12]. These interactive online textbooks are delivered in HTML format and utilize AT, like screen readers, to meet accessibility requirements. High quality alt text standards are established for complex visual elements in mechanical engineering, like phase diagrams, T-s diagrams, and output response plots. The next section will introduce the details of the guidelines developed and how they apply across materials science and engineering, thermodynamics, and control systems.

Methods

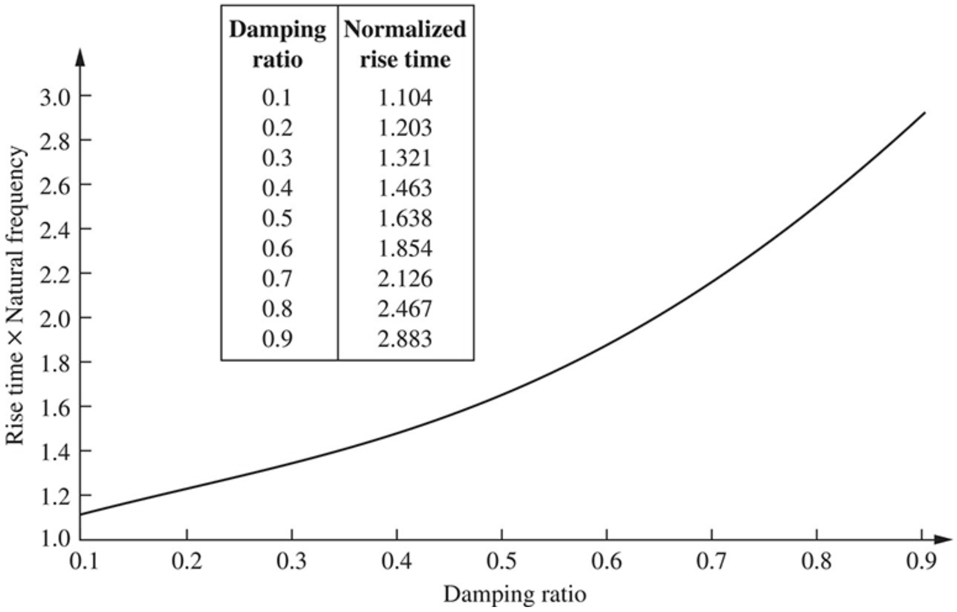
The goal of this work is to create or improve alt text of figures and animations integrated in mechanical engineering zyVersions. Several representative figures and animations from the materials science, thermodynamics, and controls zyVersions have been selected for demonstrating the standard practices the authors have developed for writing new alt text. Since the figures already included alt text before conversion to an online interactive (zyBooks) format, both the newly developed alt text and the previous alt text is presented for comparison. The newly developed alt text for figures and animations is written by content authors who are subject matter experts in the field. The standard developed by the authors for writing alt text for animations is also presented with examples from the three aforementioned interactive textbooks.

Alternative Text: Figures

Figures found in the material science, thermodynamics, and controls interactive online textbooks can include images, equations, and/or plots. Such figures appear throughout these and most other mechanical engineering textbooks, typically one to two figures per section on average, and are vital to student understanding of the course material. The tables below include representative figures from the aforementioned books and apply the alt text guidelines for figures. The previous alt text provided by the textbook publisher, the new alt text written by the present content authors, and a summary of the standard practices adapted for handling different technical figure content is given.

Many figures in control systems include plots with curves that represent the output response of the system, or values such as the damping ratio as shown in Table 1. Particularly for figures used as references in problems or examples, such as that in table 1, a quality alt text is necessary to provide students the ability to apply the data presented to solve the given problem or example.

Table 1. Figure from controls systems interactive textbook.

<table>
<tr><td>Book</td><td>Control Systems</td></tr>
<tr><td colspan="2">


</td></tr>
<tr><td>Previous alt text</td><td>"Image described by surrounding text."</td></tr>
<tr><td>New alt text</td><td>"The figure shows a plot of the rise time (\(T_r\)) times the natural frequency (\(\omega_n\) vs. damping ratio \(\zeta\). The x-axis, or damping ratio, has a limit from \(0.1\) to \(0.9\). The y-axis, or the rise time times the natural frequency, has a limit from \(1.0\) to \(3.0\). The curve is nonlinear and has a positive slope along every point. The curve begins at point (0.1,1.104) and ends at (0.9, 2.883). The 10 points used to obtain the curve are shown in a \(11 \times 2\) table. The first column lists the damping ratios (0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, and 0.9) and the second column lists the corresponding normalized rise times (1.104, 1.203, 1.321, 1.463, 1.638, 1.854, 2.126, 2.467, and 2.883)."</td></tr>
<tr><td>Standard developed</td><td>● When a plot is present, the plot title, x and y axes titles with units, limits of both the x and y axes, and a description of the response/data on the plot are needed (or as much of that information that is present on the figure).</td></tr>
</table>

Example problems in thermodynamics often involve a figure comprising a cycle schematic paired with a property diagram. The cycle schematic depicts components, like a boiler and turbine, including the phase of the working fluid and property data at each state of the cycle. A property diagram, like a *T-s* or *p-v* plot, characterizes the property data for each process of the cycle. Table 2 shows a figure taken from an example problem in the thermodynamics textbook. A comparison between the original and new alt text is listed below the figure with a summary of the alt text standards that were applied.

Table 2. Figure from thermodynamics interactive textbook.

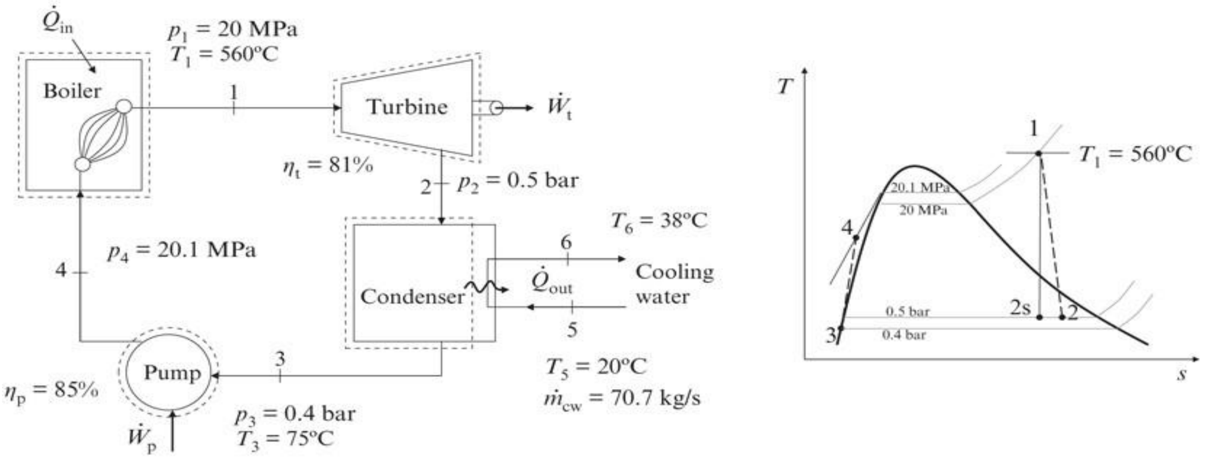
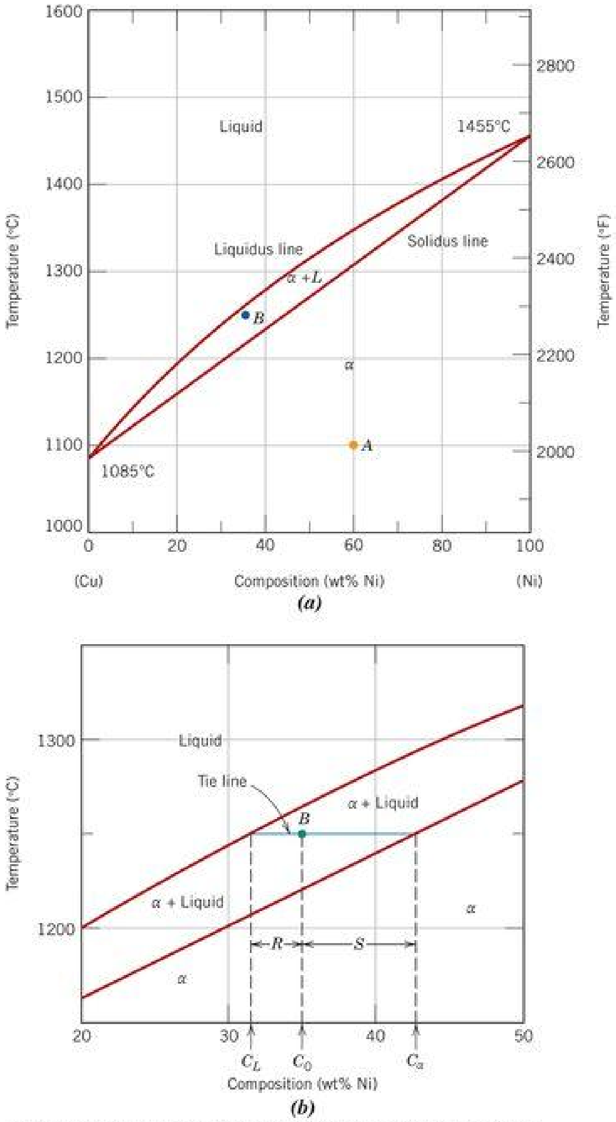
Book	Thermodynamics
	
Previous alt text	"Left: Cycle diagram from boiler to turbine (p1 = 20 MPa and T1 = 560°C), to condenser (p2 = 0.5 bar), to pump (p3 = 0.4 bar and T3 = 75°C), to boiler (p4 = 20.1 MPa). Bottom: Graph with an ascending–descending curve."
New alt text	"Left image shows a Rankine cycle with a boiler, turbine, condenser, and pump. Markings for input heat transfer Q_in dot, state 1 at p_1 equals 20 megapascals, T_1 equals 560 degrees Celsius, output work rate W_t dot, isentropic turbine efficiency equals 81 percent, state 2 at p_2 equals 0.5 bar, temperature difference between states 5 and 6 with cooling water at T_5 equals 20 degrees Celsius, cooling water mass flow rate m_cw dot equals 70.7 kilograms per second, and T_6 equals 38 degrees Celsius, state 3 at p_3 equals 0.4 bar, T_3 equals 75 degrees Celsius, input work rate W_p dot, isentropic pump efficiency equals 85 percent, and state 4 at p_4 equals 20.1 megapascals. Right image shows a temperature (T) versus specific entropy (s) plot with markings for state 1, 2, 2s, 3, 4s, pressure 20.1 megapascals and T_1 equals 560 degrees Celsius at state 1, 0.5 bar at state 2 and 2s, 0.4 bar state state 3, and 20 megapascals at state 4."
Standards developed	● State property data for cycles is described in a sequential manner beginning with state 1. ● Figures with multiple plots or graphs are described from left to right and top to bottom. ● Property diagrams are described with known state property data and process idealizations between states.

Table 3 shows an example of a static figure from the materials science textbook. The previous alt text provides minimal details such as the starting and ending points of the lines and the fact that both lines are increasing. Because this figure is used as a reference in multiple sections throughout the book, information that a sighted student can easily discern needs to be explained in specific detail. Vital information about the graph, such as labels and ranges of the x and y axes, descriptions of the different regions, and more specific descriptions of the locations of Point A and Point B, were added to the alt text so that students using AT can have a more complete understanding of what is happening in both graphs.

Table 3. Figure from material science interactive textbook.

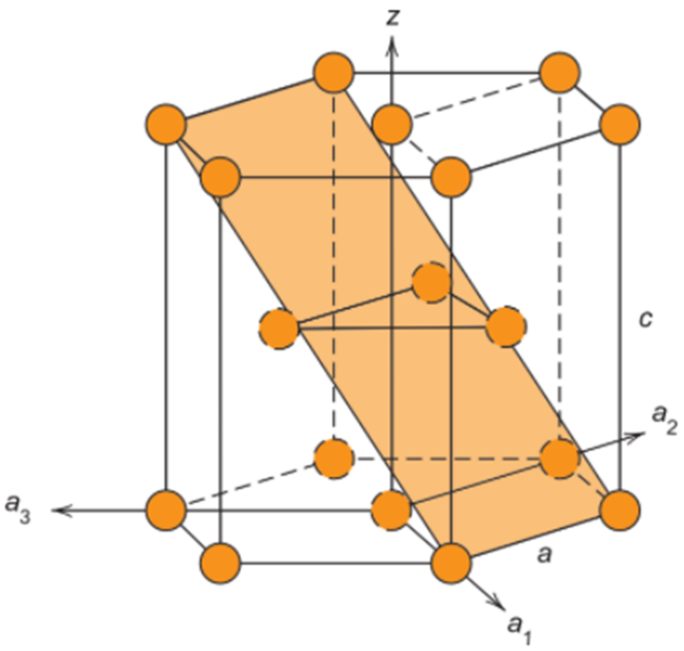
<table>
<tr><td>Book</td><td>Materials science</td></tr>
<tr><td colspan="2">

Adapted from Phase Diagrams of Binary Nickel Alloys, P. Nash, Editor, 1991.
Reprinted by permission of ASM International, Materials Park, OH.</td></tr>
</table>

Previous alt text	"Temperature versus composition percent graph shows solidus and liquidus lines increasing from 1085 to 1455 degree Celsius, point A below solidus line and point B between solidus and liquidus lines."
New alt text	"The copper-nickel phase diagram is shown in (a), and a zoomed in portion of the copper-nickel phase diagram is shown in (b). (a) The y-axis shows temperature in degrees celsius, and the x-axis represents alloy composition in terms of wt% Ni (0 on the x-axis represents 0 wt% Ni, and 100 wt% Cu, while 100 on the x-axis represents 100 wt% Ni and 0 wt% Cu). Two phase lines bow away from each other at 0 wt% Ni, 1085 \(^{\circ}\)C, and reconnect at 100 wt% Ni, 1455 \(^{\circ}\)C. The lower phase line is labeled solidus, and the upper phase line is labeled liquidus. Three distinct regions exist: below the solidus phase line, between the solidus and liquidus phase lines, and above the liquidus phase line. Point A is below solidus line at 60 wt% Ni, 1100 \(^{\circ}\)C. Point B is between solidus and liquidus lines at about 35 wt% Ni, 1250 \(^{\circ}\)C. (b) The zoomed in copper-nickel phase diagram is from 20 wt% Nickel to 50 wt% Nickel on the x-axis, and 1150 Celsius to 1350 Celsius on the y-axis. A phase line separates the solid alpha from the alpha+liquid region, extending from 20 wt% Nickel at about 1160 celsius to 50 wt% Nickel at about 1275 celsius. A higher temperature phase line separates the alpha+liquid region from the liquid region, extending from 20 wt% Nickel at 1200 celsius to 50 wt% Nickel at about 1325 celsius. Point B is located at about 35 wt% Nickel and 1250 Celsius, indicating an alloy with a composition of 35 wt% Nickel, C_0. A horizontal line, called a 'tie line', connects the higher temperature phase line to point B to the lower temperature phase line. The tie line intersection to the higher temperature phase line is at 1250 Celsius and about 32 wt%Nickel, C_L. The tie line intersection to the higher temperature phase line is at 1250 Celsius and about 43 wt% Nickel, C_R. The separation between C_L and C_0 is labeled R. The separation between C_R and C_0 is labeled S."
Standard developed	● Key points on graphs are labeled. ● When regions in the graph are important, the regions are specified in the alt text. ● Start and end points for lines are indicated to help define boundary regions. ● If a topic is not immediately introduced with the figure, or is covered more in depth later, extra detail may not be necessary in an initial figure. ● When the figure is expected to be a 'reference', or is often used as a comparison, a generalized description is used.

Some of the interactive question sets that were added to the textbook required the creation of new figures, for which alt text needed to be written. Table 4 shows an example of such a figure from the materials science interactive textbook. Students have encountered a hexagonal close-packed unit cell before the question set, so the unit cell is not described in significant detail. The focus of the alt text for this figure is on the locations of the four axes and the plane in relation to the atoms in the unit cell.

Table 4. Figure from material science interactive textbook used for question set.

Book	Material science
	
Previous alt text	No previous alt text because this image was created for the interactive book.
New alt text	"A drawing of a hexagonal close packed unit cell with unit cell edge length \(a\), height \(c\), and a four-axis coordinate system \((a_1, a_2, a_3, z)\) with the origin at the center of the bottom hexagonal face. The \(a_1\)-axis goes from the center atom of the bottom hexagonal face through the front right atom on the bottom hexagonal face. The \(a_2\)-axis goes from the center atom of the bottom hexagonal face through the back-right atom of the bottom hexagonal face. The \(a_3\)-axis goes from the center atom of the bottom hexagonal face through the left-side atom of the bottom hexagonal face. The \(z\)-axis goes from the center atom of the bottom hexagonal face through the center atom of the top hexagonal face. A plane passes through the left-side atom and back-left atom of the top hexagonal face and the front-right atom and right-side atom of the bottom hexagonal face."
Standard developed	● Descriptions of figures used for question sets explain the figure with enough detail to allow for answering the accompanying questions without giving details and/or hints that do not appear in the image. ● Parts of a figure/image that have been used previously and are described in the alt text for previous figures/images are not described again in detail.

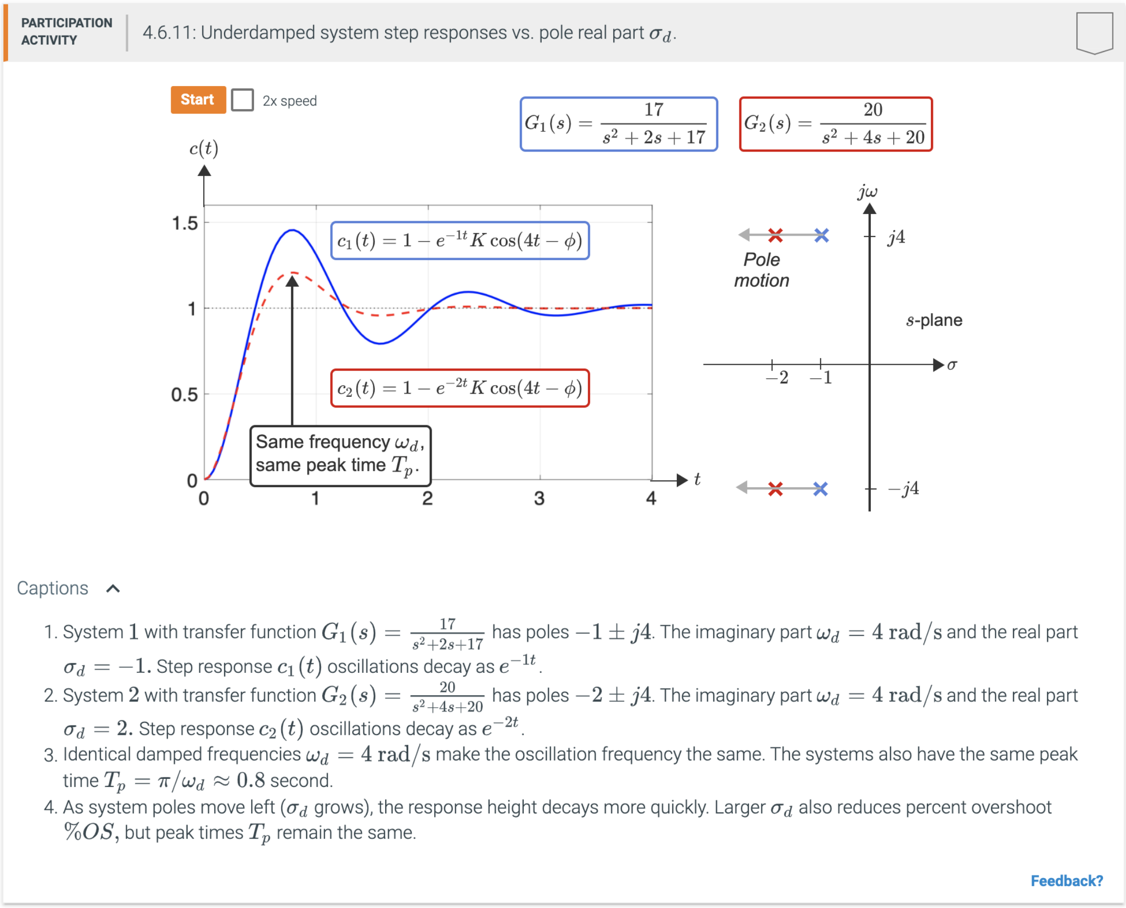
Alternative Text: Animations

Animations within online mechanical engineering textbooks are used for visualization and clarification of complex concepts and problem procedures. As the student progresses through the steps in the animation, LaTeX equations, images, and/or plots are unveiled and moved across the animation window. Every step in the animation includes a concise caption that can be read by AT tools, such as screen readers, that describes the major takeaway point of that step. Unfortunately, AT tools cannot read or describe the elements in the animation window, therefore alt text needs to be developed for animations to be fully accessible.

The authors' process in designing animations begins with outlining the steps of the animation. The outline describes details of the movements and actions that occur during the animation and is used as a starting point when creating the alt text. Standard practice in creating the animations for the zyVersion is to sequentially unveil/move elements found in the final animation static image. Since elements in the animation do not generally disappear, describing the final animation static image in the alt text provides the minimum necessary important information for students. However, in many cases, additional alt text is added to describe the dynamic aspect of the animation, allowing the student to tie together the different aspects in the animation. The tables below provide examples of alt text for animations developed. Note, since the animations were created solely for the use in the interactive online textbook, no previous alt text existed, except in cases where the interactive animation was based directly on a pre-existing figure.

The following control systems animation shows the relationship between two plots, the output response plot on the left and the pole-zero plot on the right. The alt text for the animation presented in Table 5 describes the final static image as well as provides a description of the movement of the elements and how they affect the response plot. Movement details and the effect of the movement is an integral part of the learning provided by the animation, therefore such details should also be added to the alt text.

Table 5. Animation from the controls systems interactive textbook.

<table>
<tr><td><i>Book</i></td><td>Control Systems</td></tr>
<tr><td colspan="2">


PARTICIPATION ACTIVITY

4.6.11: Underdamped system step responses vs. pole real part σ_d.

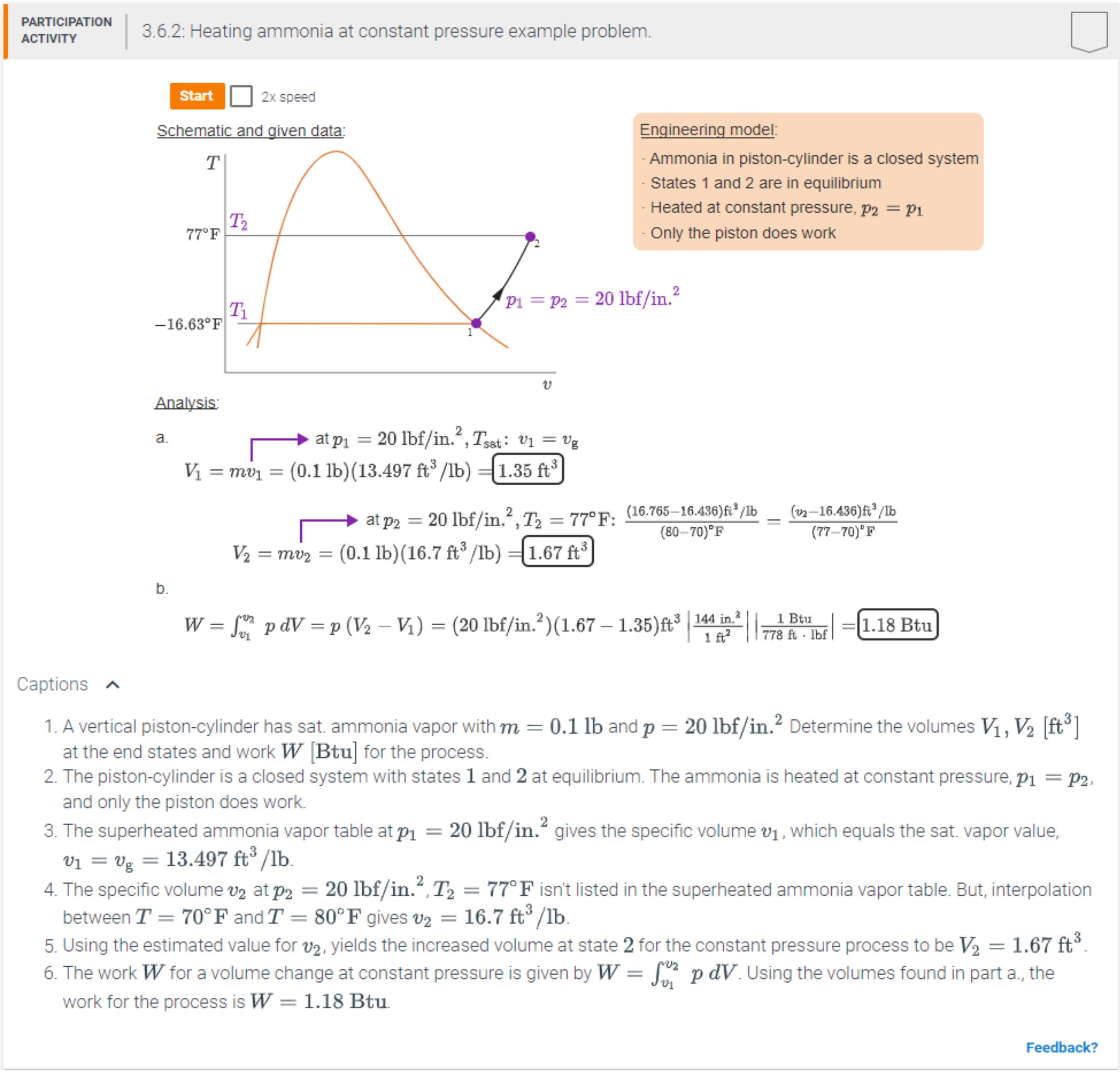
Captions

1. System 1 with transfer function $G_1(s) = \frac{17}{s^2+2s+17}$ has poles $-1 \pm j4$. The imaginary part $\omega_d = 4$ rad/s and the real part $\sigma_d = -1$. Step response $c_1(t)$ oscillations decay as e^{-1t}.
2. System 2 with transfer function $G_2(s) = \frac{20}{s^2+4s+20}$ has poles $-2 \pm j4$. The imaginary part $\omega_d = 4$ rad/s and the real part $\sigma_d = 2$. Step response $c_2(t)$ oscillations decay as e^{-2t}.
3. Identical damped frequencies $\omega_d = 4$ rad/s make the oscillation frequency the same. The systems also have the same peak time $T_p = \pi/\omega_d \approx 0.8$ second.
4. As system poles move left (σ_d grows), the response height decays more quickly. Larger σ_d also reduces percent overshoot $\%OS$, but peak times T_p remain the same.

Feedback?
</td></tr>
<tr><td><i>New alt text</i></td><td>"On the left, a plot of the output unit step response for two transfer functions is shown. The plot has the output \(c(t)\) on the y-axis, with limits from \(0\) to around \(1.6\), and time \(t\) on the x-axis has limits from \(0\) to \(4\). On the right, the \(s\)-plane plot is shown with the real axis \(\sigma\) on the x-axis, and the imaginary axis \(j\omega\) on the y-axis. As complex conjugate poles move horizontally, from \(-1\pm j4\) to \(-2 \pm j4\) and beyond, the decay of the response becomes faster and percent overshoot becomes smaller, but the frequency \(\omega_d\) and peak time \(T_p\) remain the same. The poles at \(-1\pm j4\), corresponding to \(G_1(s) = \frac{17}{s^2+2s+17}\), have a step response of \(c_1(t)=1-e^{-1t}K\cos(4t-\phi)\). The poles at \(-2 \pm j4\), corresponding to \(G_2(s) = \frac{20}{s^2+4s+20}\), have a step response of \(c_2(t)=1-e^{-2t}K\cos(4t-\phi)\). Both \(c_1(t)\) and \(c_2(t)\) have a steady state value of one."</td></tr>
<tr><td><i>Standard developed</i></td><td>● Elements of the animation tend to be described from left to right
● If necessary, a description of the movement of elements within the animation are added to the final static image alt text</td></tr>
</table>

Thermodynamics problems are solved with a systematic problem-solving approach. The approach presents the schematic and given data, lists the problem idealizations in the engineering model, and applies constitutive equations to analyze the problem and yield solutions to unknown quantities. The authors chose to reinforce this methodology with the animations created for example problems, as shown for example in Table 6.

Table 6. Animation from the thermodynamics interactive textbook.

<table>
<tr><td><i>Book</i></td><td>Thermodynamics</td></tr>
<tr><td colspan="2">
PARTICIPATION ACTIVITY 3.6.2: Heating ammonia at constant pressure example problem.
Start ☐ 2x speed
Schematic and given data:

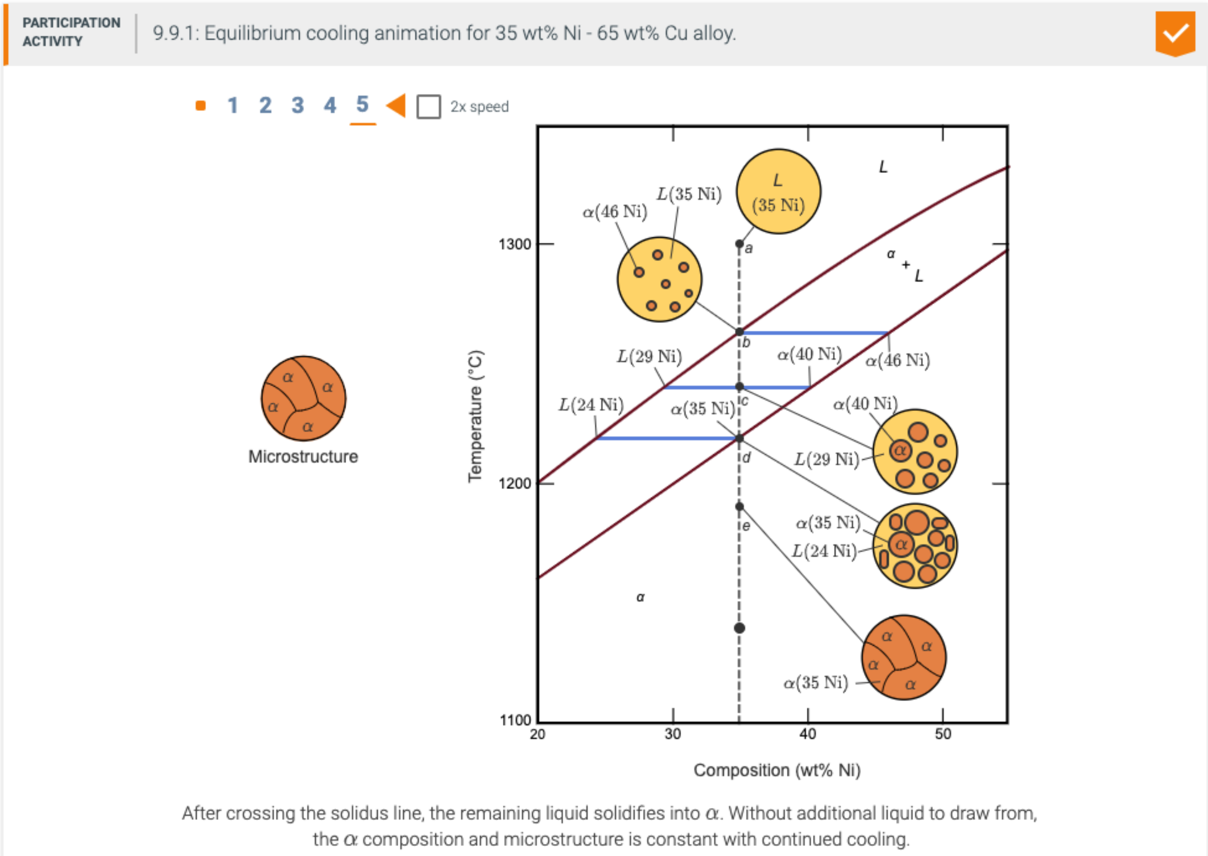
Engineering model:
· Ammonia in piston-cylinder is a closed system
· States 1 and 2 are in equilibrium
· Heated at constant pressure, $p_2 = p_1$
· Only the piston does work
Analysis:
a. at $p_1 = 20\ \mathrm{lbf/in.}^2, T_{\mathrm{sat}}:\ v_1 = v_g$
$V_1 = mv_1 = (0.1\ \mathrm{lb})(13.497\ \mathrm{ft}^3/\mathrm{lb}) = \boxed{1.35\ \mathrm{ft}^3}$
at $p_2 = 20\ \mathrm{lbf/in.}^2, T_2 = 77°\mathrm{F}:\ \frac{(16.765-16.436)\mathrm{ft}^3/\mathrm{lb}}{(80-70)°\mathrm{F}} = \frac{(v_2-16.436)\mathrm{ft}^3/\mathrm{lb}}{(77-70)°\mathrm{F}}$
$V_2 = mv_2 = (0.1\ \mathrm{lb})(16.7\ \mathrm{ft}^3/\mathrm{lb}) = \boxed{1.67\ \mathrm{ft}^3}$
b.
$W = \int_{v_1}^{v_2} p\,dV = p\,(V_2 - V_1) = (20\ \mathrm{lbf/in.}^2)(1.67 - 1.35)\mathrm{ft}^3 \left|\frac{144\ \mathrm{in.}^2}{1\ \mathrm{ft}^2}\right| \left|\frac{1\ \mathrm{Btu}}{778\ \mathrm{ft\cdot lbf}}\right| = \boxed{1.18\ \mathrm{Btu}}$
Captions
1. A vertical piston-cylinder has sat. ammonia vapor with $m = 0.1\ \mathrm{lb}$ and $p = 20\ \mathrm{lbf/in.}^2$ Determine the volumes $V_1, V_2\ [\mathrm{ft}^3]$ at the end states and work $W\ [\mathrm{Btu}]$ for the process.
2. The piston-cylinder is a closed system with states 1 and 2 at equilibrium. The ammonia is heated at constant pressure, $p_1 = p_2$, and only the piston does work.
3. The superheated ammonia vapor table at $p_1 = 20\ \mathrm{lbf/in.}^2$ gives the specific volume v_1, which equals the sat. vapor value, $v_1 = v_g = 13.497\ \mathrm{ft}^3/\mathrm{lb}$.
4. The specific volume v_2 at $p_2 = 20\ \mathrm{lbf/in.}^2, T_2 = 77°\mathrm{F}$ isn't listed in the superheated ammonia vapor table. But, interpolation between $T = 70°\mathrm{F}$ and $T = 80°\mathrm{F}$ gives $v_2 = 16.7\ \mathrm{ft}^3/\mathrm{lb}$.
5. Using the estimated value for v_2, yields the increased volume at state 2 for the constant pressure process to be $V_2 = 1.67\ \mathrm{ft}^3$.
6. The work W for a volume change at constant pressure is given by $W = \int_{v_1}^{v_2} p\,dV$. Using the volumes found in part a., the work for the process is $W = 1.18\ \mathrm{Btu}$.
 </td></tr>
<tr><td><i>New</i></td><td>"A temperature (T) versus specific volume plot shows markings for temperature at state 1</td></tr>
</table>

alt text	equals -16.67 degrees Fahrenheit, temperature at state 2 equals 77 degrees Fahrenheit, and pressure at state 1 equals pressure at state 2 equals 20 psi. A box shows the engineering model listing the problem assumptions and idealizations. The analysis shows calculations for volume at state 1 equals 1.35 cubic feet, volume at state 2 equals 1.67 cubic feet, and process work equals 1.18 Btu."
Standard developed	● Example problem animations are described in the order schematic and given data, engineering model, and analysis. ● Property diagrams are described with known state property data and process idealizations between states. ● Key calculations and idealizations are described for each state, while summarizing the problem-solving process.

In materials science and engineering, phase diagrams are one of the most complicated topics that commonly leads to student confusion. Equilibrium cooling, which involves the use of tie lines to find the compositions of specific phases of a multiphase material, is a topic that is particularly difficult for students to understand. Because of this, an animation was created that walks students step-by-step through the process of equilibrium cooling of a nickel-copper alloy. Because each animation action is necessary to help the students understand the process, a detailed description of the animation actions was included in the alt text, instead of including only a description of the final static image. Screenshots and detailed descriptions of the animation steps and animation actions for the equilibrium cooling animation are included in Appendix A. Table 7 includes only the final static image and a description of the final static image as it appears in the alt text for the animation in the interactive materials science textbook. However, Table 7 does include the standards developed for the entire animation, not just the final static image.

Table 7. Animation from the materials science interactive textbook.

<table>
<tr><td>Book</td><td>Materials science</td></tr>
<tr><td colspan="2">Animation static final image: (Note: Screenshots of animation steps are included in Appendix A)



PARTICIPATION ACTIVITY | 9.9.1: Equilibrium cooling animation for 35 wt% Ni - 65 wt% Cu alloy.

After crossing the solidus line, the remaining liquid solidifies into α. Without additional liquid to draw from, the α composition and microstructure is constant with continued cooling.</td></tr>
<tr><td>New alt text</td><td>"Static view (final step): A zoomed in version of the copper-nickel phase diagram unveils. The y-axis shows temperature from 1100\(^{\circ}\)C to 1400\(^{\circ}\)C. The x-axis shows the nickel concentration from 20 wt% Ni to 60 wt% Ni. The solidus line extends from about 20 wt% Ni, 1150\(^{\circ}\)C to about 60 wt% Ni, 1295\(^{\circ}\)C. The liquidus line extends from about 20 wt% Ni, 1200\(^{\circ}\)C to about 60 wt% Ni, 1350\(^{\circ}\)C. An alloy composition is shown as a dotted vertical line at 35 wt%Ni-65 wt% Cu. The alloy composition is shown to cool from Point a to point e. Point a is at 35 wt%Ni, 1300\(^{\circ}\)C. Point b is at 35 wt%Ni, 1260\(^{\circ}\)C. Point c is at 35 wt%Ni, 1240\(^{\circ}\)C. Point d is at 35 wt%Ni, 1220\(^{\circ}\)C. Point e is at 35 wt%Ni, 1175\(^{\circ}\)C. Tie lines are used for b, c, and d to determine phase compositions. CIrcular insets show the alloy's microstructure during cooling. The size of solid alpha that forms increases as cooling continues below the liquidus line, until no liquid remains below the solidus line and there is only solid alpha."
Note: Alt Text for individual animation steps included in Appendix A</td></tr>
<tr><td>Standard developed</td><td>● For descriptions of complicated animation actions that are essential to student learning, each animation step is described in detail instead of just describing the final static image then adding small details about animation motions.</td></tr>
</table>

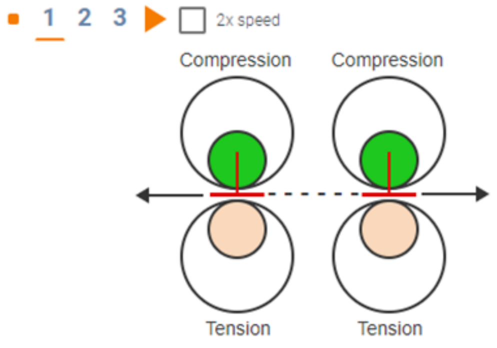
	● For descriptions of animations with a large number of steps, the step captions are included in the alt text in order to divide the descriptions of animation actions into steps. ● Animations that include graphs include a detailed description of the graph if the graph does not appear outside of the animation. If the graph is included elsewhere, a detailed description of the graph is not necessary. Instead a short description of the most relevant parts of the graph is included in the alt text.

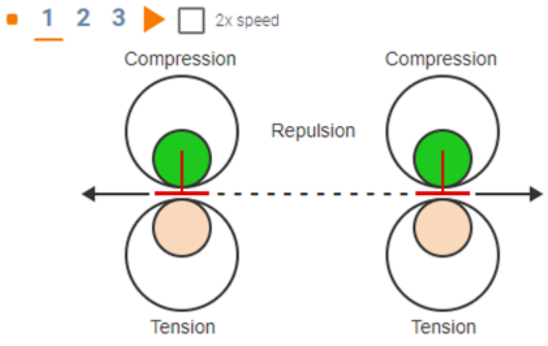
During the development of the interactive materials science textbook, figures were found that depicted multiple states of a process without showing the actions that are involved between the states. Because interactive animations were being added, it was decided that such figures would be turned into interactive animations. Table 8 shows an animation that was adapted from a static figure, which showed the interactions between two edge dislocations of the same sign and two edge dislocations of opposite signs. The alt text of the original figure only says that two edge dislocations of the same sign lie on the same plane and two edge dislocations of opposite signs lie on the same plane, but there is not a detailed description of how the edge dislocations are depicted in the image. This detailed description, as well as a description of the motion of the edge dislocations relative to each other that show either repulsion or attraction, was added to the alt text of the animation that was adapted from the figure.

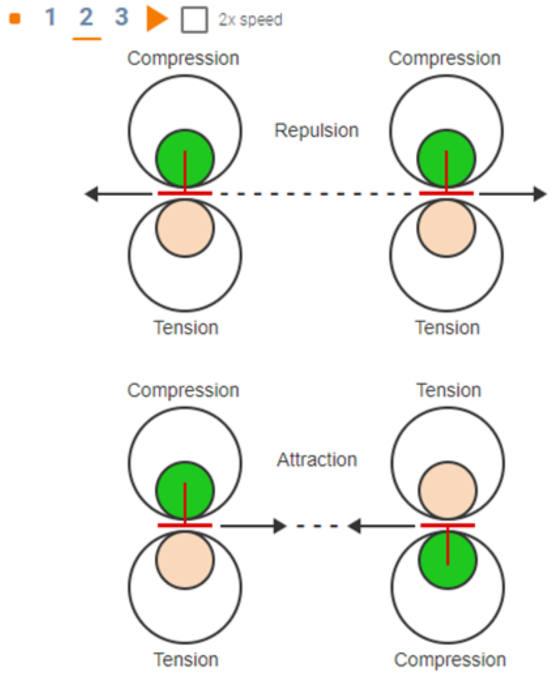
Table 8. Animation adapted from the static figure from the materials science interactive textbook.

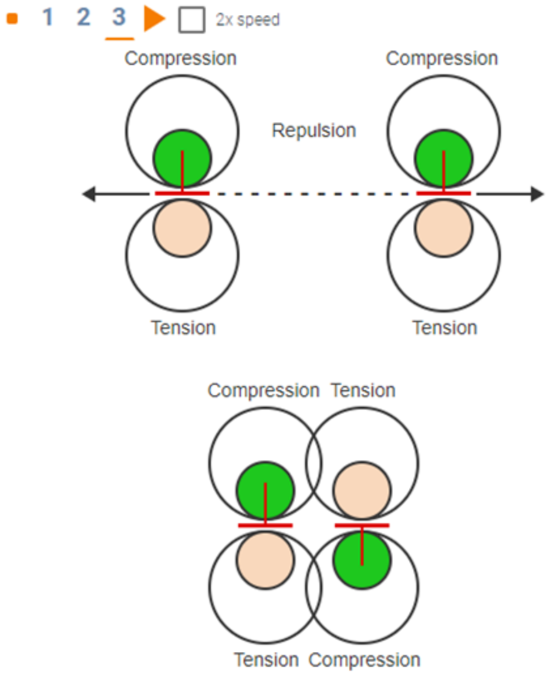
Book	Materials science

Animation Steps:

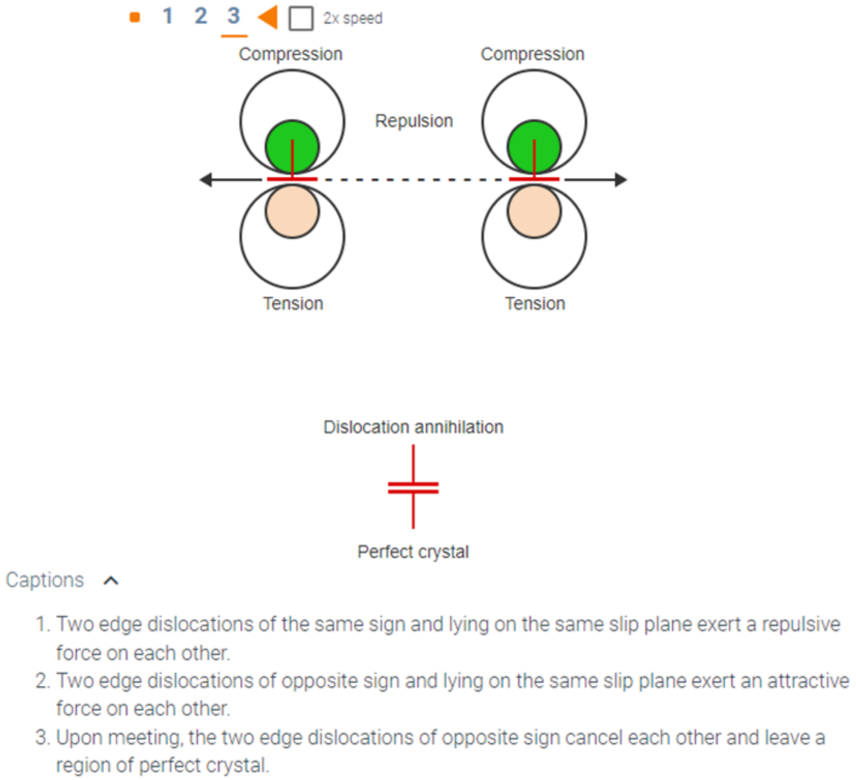








Animation final static image:



1. Two edge dislocations of the same sign and lying on the same slip plane exert a repulsive force on each other.
2. Two edge dislocations of opposite sign and lying on the same slip plane exert an attractive force on each other.
3. Upon meeting, the two edge dislocations of opposite sign cancel each other and leave a region of perfect crystal.

Previous alt text	"Two edge dislocations of the same sign and lying on the same slip plane exert a repulsive force on each other; C and T denote compression and tensile regions, respectively. (b) Edge dislocations of opposite sign and lying on the same slip plane exert an attractive force on each other. Upon meeting, they annihilate each other and leave a region of perfect crystal."
New alt text	"Two groups of vertically aligned circles each with an inverted T in the middle appear in the top middle of the animation screen. Each group of circles includes two larger circles arranged vertically. The top large circle has a smaller circle inside at the bottom and the bottom large circle has a smaller circle inside at the top. The horizontal part of the inverted T lies in between the two large circles in each group. The top circles are labeled 'Compression' and the bottom circles are labeled 'Tension'. A dashed line appears in between the circles aligned with the horizontal part of the inverted Ts. Horizontal arrows appear pointing out at each end of the dotted line. The groups of circles move horizontally apart from each other. The word 'Repulsion' appears between the circles. Another similar group of circles appear below the first with the group of circles on the right inverted from the previous group. The labels are switched on the right circles from the previous image, with the label 'Tension' on top and the label 'Compression' on the bottom and the inverted T becomes a T. Arrows appear pointing in with a dotted line in between aligned with the horizontal parts of the inverted T and T. The word 'Attraction' appears between the circles. The Attraction circles move towards each other until they overlap. The circles disappear and only the inverted T and the T are left. The text 'Dislocation annihilation' appears above the inverted T and T. The text 'Perfect crystal' appears below the inverted T and T. "
Standard developed	● Figures that show static images of different states without showing intermediate actions are generally changed to interactive animations.

	● Animations that are adapted from static figures describe each step in detail because the animation actions are what distinguish the animation from the static figure. ● Complex animations composed primarily of visual elements such as images, graphs, or diagrams require detailed descriptions of the visual elements in the alt text.

Discussion

Static figures, which appear throughout mechanical engineering textbooks, along with the interactive animations that have been added to the online mechanical engineering textbooks, often contain visual elements that are critical for student understanding. During the process of adding interactivity to the materials science, control systems, and thermodynamics textbooks, the content authors wrote descriptive alt text for the visual elements in the animations and figures and established guidelines that will be used in the future as additional print textbooks are converted to the zyBooks format. These guidelines for figures and animations are discussed in this section.

Alternative Text: Figures

To address the challenges of describing the technical content in the figures presented above, the following guidelines were established:

1. Figures with multiple plots or graphs are described from left to right and top to bottom.
2. Figures are described in a natural or sequential manner that does not increase the cognitive load.
3. For figures with plots: the title, x and y axes titles with units, range and limits of both the x and y axes, and labeling of key points in the data and/or regions characterized by the plot.
4. For figures used for learning questions: reinforce information on the x and y axes of plots, providing a complete description without unveiling information/answer that affects the learning benefit to students.
5. LaTeX is used to present mathematical equations rather than standard text, as screen readers can recognize equations and variables.
6. Starting and end points for lines that create special regions are described, along with the regions when they easily fit in.

With respect to alt text for figures, as can be seen from Tables 1-4, the alt text previously provided was subpar and provided the student with little to no information of the details presented. Tables 1-4 show figures that are either used as a reference for example problems in a specific chapter, or as a baseline reference with which any student in the subject should be familiar. Many professors encourage students to keep books used in the course as reference, but for students relying on screen readers, the figure alt text often does not provide reference quality information that can be useful in the future.

Textbooks typically describe a trend in a graph or figure in the body text, and expect the reader to look at a graph and immediately see the trend. Alt text for such figures tend to lack useful descriptions (e.g. "Image described by surrounding text." as shown in Table 1). In other cases, the alt text is designed specifically for visual reading (e.g. "Cycle diagram from boiler to turbine p1 = 20 MPa and T1 = 560°C" as shown in Table 2), but tends to neglect details, like efficiency and mass flow rate, that are printed on the image. Students relying on screen readers are not able to quickly glance at a figure, then look through the text for additional information about specific points in the figure. Therefore, the figure should be fully described in the alt text. While it is impossible to fully convey both contextual and descriptive aspects perfectly succinctly simultaneously, the standards developed for figures should aid in creating high quality alt text that prevents students relying on screen readers from having to search for information in the body text.

A distinction is often made between what the figure is showing at a surface level, and what the figure is meaning to convey on a scientific level. Often, alt text focuses on one or the other, but rarely both simultaneously. Alt text focusing only on the technical surface features, as shown in the figure of Table 3 (e.g. Point A is here, Point B is here, and Point C is here), are helpful for visualizing specific points, but may be a memorization overload without getting the student to understand trends that can be applied to similar situations. Conversely, alt text focusing only on the generalized scientific meaning may not give sufficient reference points to help understanding long term ("This line increases" is different from "this line always starts at zero and increases to a maximum value of..."). Applying alt text in a format that gives both surface and deeper meanings can help students understand information easier, without having to search from the figure back to the text and back to the figure multiple times.

Alternative Text: Animations

The previous standards for figures are combined with additional guidelines that are established for animations:

1. For animations with minimal movement, a description of the movement for each action is added to the final static image.
2. For more complex animations where the animation actions are essential to student learning, the animation actions in each step are described in detail instead of just adding a short description to the final static image.
3. For animations with a large number of steps (e.g. 5-8 steps), the step captions are added

to divide the descriptions of actions by animation steps.

4. Animations that are adapted from static figures describe each step in detail because the animation actions are what distinguish the animation from the static figure.
5. Complex animations composed primarily of visual elements such as images, graphs, or diagrams require detailed descriptions of the visual elements in the alt text.
6. For example problem animations, elements are described in the order schematic and given data, engineering model, and analysis.
7. For mathematical calculations, idealizations are described for each state, while summarizing the problem-solving process.

Animations are a combination of several figure elements (e.g. plots, images, and equations), so the high quality alt text standards established for figures are also applied. But, animations also incorporate a dynamic aspect with moving elements from one position to another to connect concepts. To incorporate the dynamic portion, animation standards were developed that cover many of the scenarios seen throughout the different animations.

When needed and when important to the student's understanding, additional alt text should be added to describe the movement present in the animation. As shown in Table 5, additional alt text was added to the description of the final static image to describe how the movement of the poles portrayed with "X's", influenced the final output response. Since the animation only included minimal movement (e.g. poles moving horizontally as indicated by the gray arrow), only minimal additions to the static image alt text was needed.

When the animation is solving a problem similar to an example, such as that found in Table 6, the alt text should present the information in a similar order to the examples already present (e.g. present the givens, assumptions, and then begin the analysis). Keeping the same format will provide continuity between examples and animation alt text for students.

Complex or very visual animations where student learning relies heavily on the description of the movement of the elements should include alt text that describes the content and movement introduced at every step. In particular, animations that do not include many equations, but instead rely on the movement of images, benefit from alt text being presented for every step of the animation. Tables 7 and 8 include animations that rely heavily on visuals and movement, therefore alt text that clearly describes the movement and unveiling of elements for every step of the animation.

Conclusions and Future Work

Several standards have been established that apply to writing alt text for both figures and animations in zyVersion. Representative examples that apply the standards developed from the materials science, thermodynamics, and control systems interactive textbook have been presented.

Although the authors who created the animations, who are subject matter experts, wrote the new alt text for figures and animations in the zyVersion, the alt texts for figures and graphs could have been written by accessibility coordinators or other freelance staff, using the developed standards. Subject matter experts, such as the authors, could then verify the accuracy of the text descriptions. For example, many graphs are described in terms of initial and final points and other key locations, which can be discerned and written into the alt text then reviewed by a subject matter expert.

Further research is to be done to test the efficacy of the new alt text developed. To examine the effectiveness of the alt text developed for figures, a survey will be conducted that asks students to replicate the figure both with the previous alt text and the new alt text. In addition, for figures used as references for end of chapter or example problems, students will be asked to complete the problem given the previous and new alt text. Finding a middle ground between specific and general information is important. Continuing to zero in on this value is very beneficial and can be expanded by having follow up research using question sets and alt text related content with various degrees of either.

As additional textbooks are moved into the zyBooks format, alt text for figures will be modified and alt text for the interactive animations that will be added to the online textbooks will be written by the content authors as the animations are created. Not every textbook can be immediately and completely converted to these new standards for alt text, but because these zyVersion are regularly updated, each new update could include more alt text, initially focusing on key figures and graphs, until the alt text is completed for the entire book. The guidelines described above, and any additional guidelines that might be established through future research, will not only be used by the content authors for writing the descriptive alt text for future mechanical engineering textbooks converted to the zyBooks format, but can also be used by others for describing visual elements in engineering e-textbooks.

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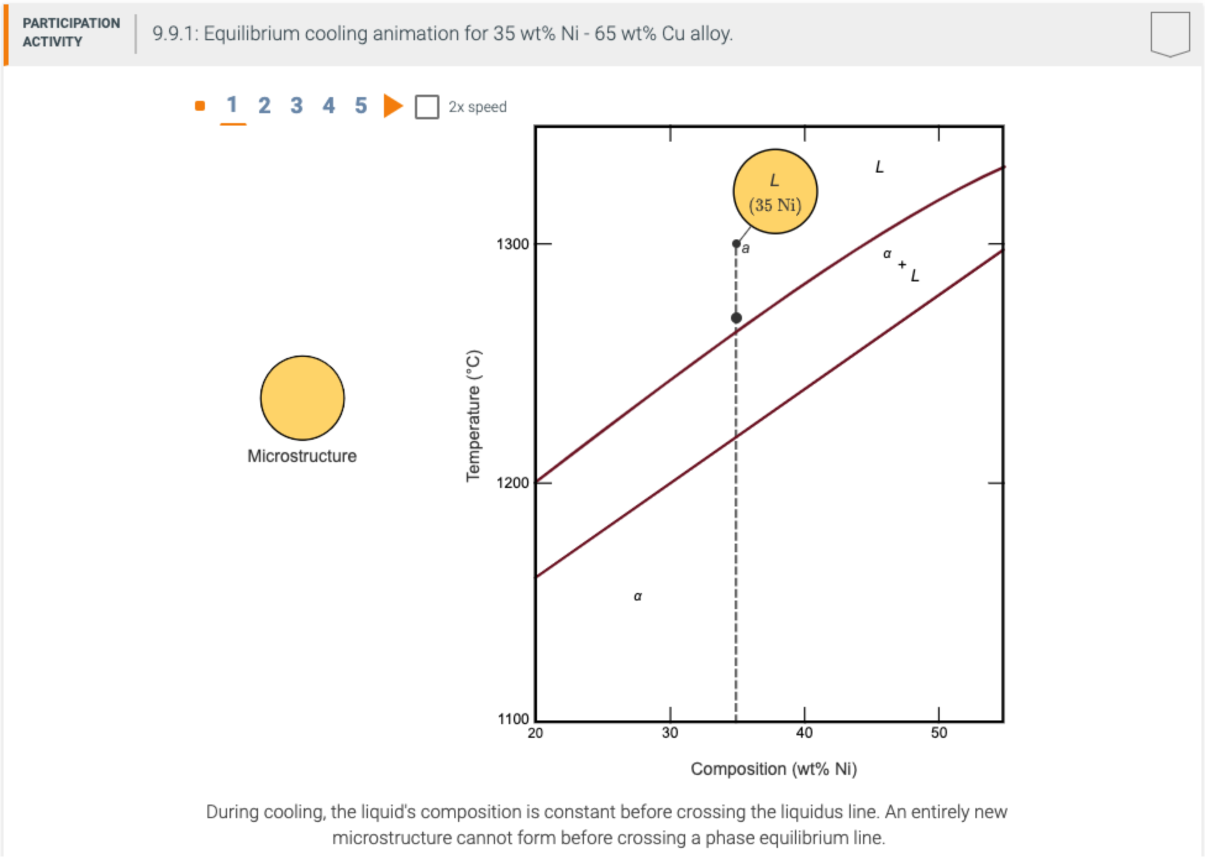
Appendix A

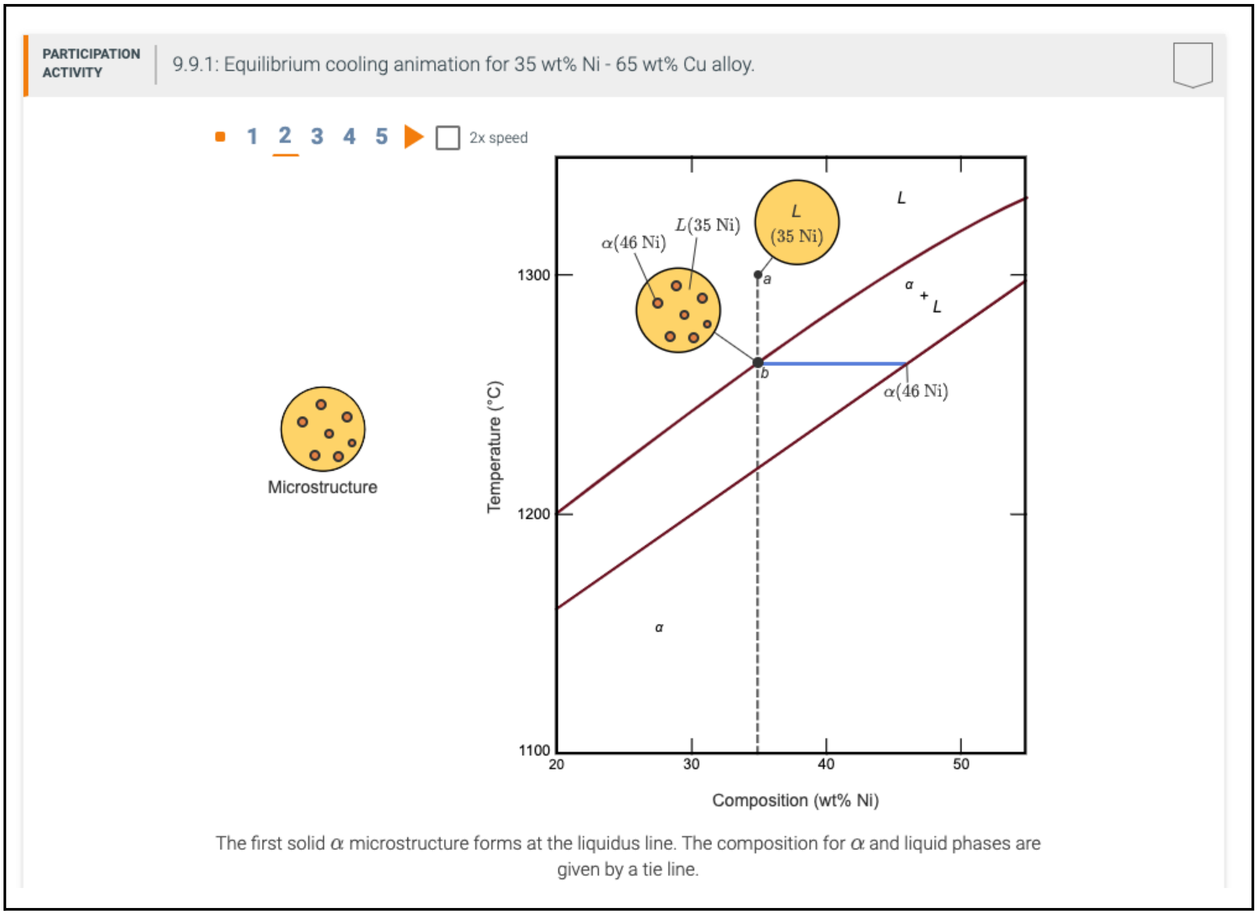
The table below shows the steps in the animation that leads to the final static image presented in Table 7. The new alt text presented at the end of the table demonstrates descriptions of the animation steps and animation actions for the equilibrium cooling animation.

Table A1. Animation from the materials science interactive textbook.

Book	Materials science
	

PARTICIPATION ACTIVITY 9.9.1: Equilibrium cooling animation for 35 wt% Ni - 65 wt% Cu alloy.

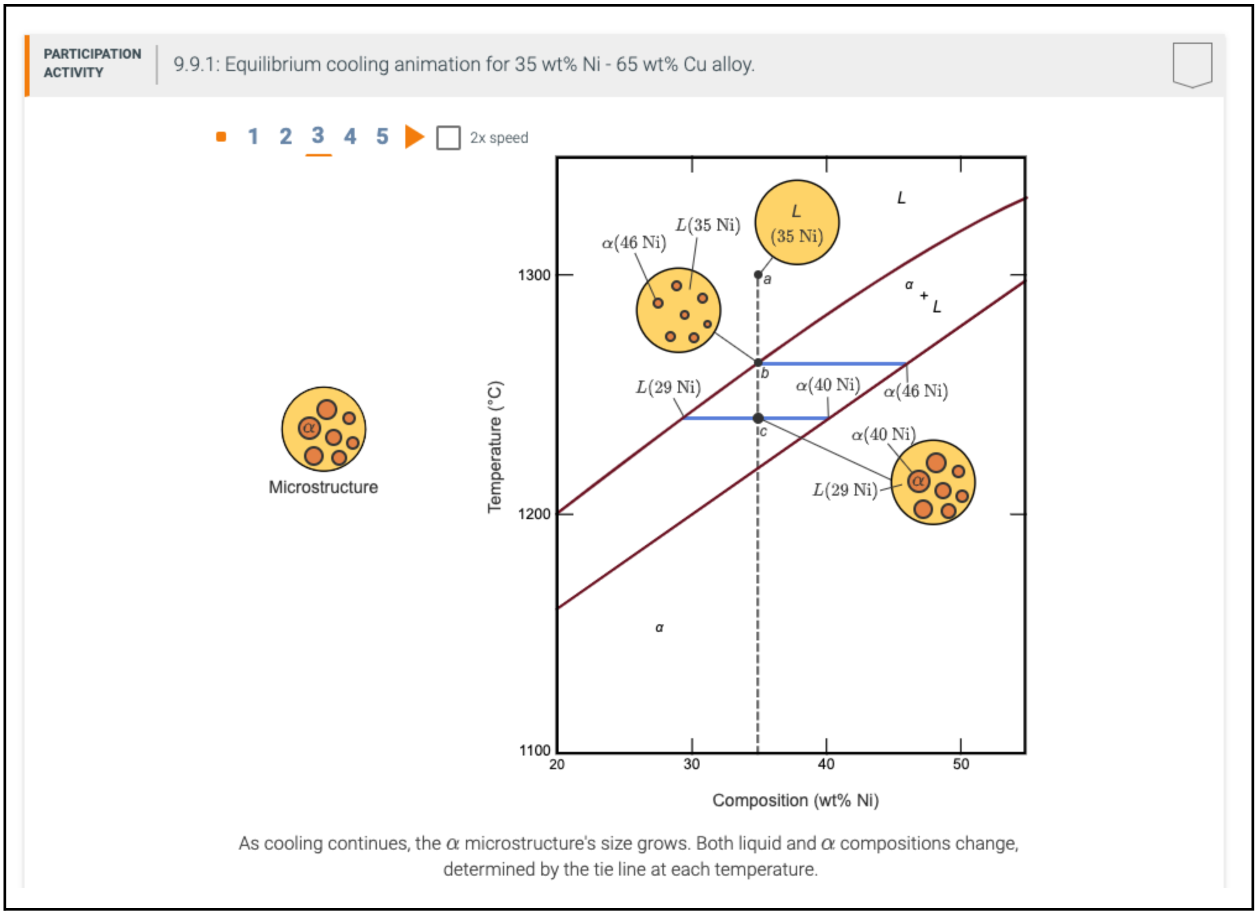
During cooling, the liquid's composition is constant before crossing the liquidus line. An entirely new microstructure cannot form before crossing a phase equilibrium line.



PARTICIPATION ACTIVITY

9.9.1: Equilibrium cooling animation for 35 wt% Ni - 65 wt% Cu alloy.

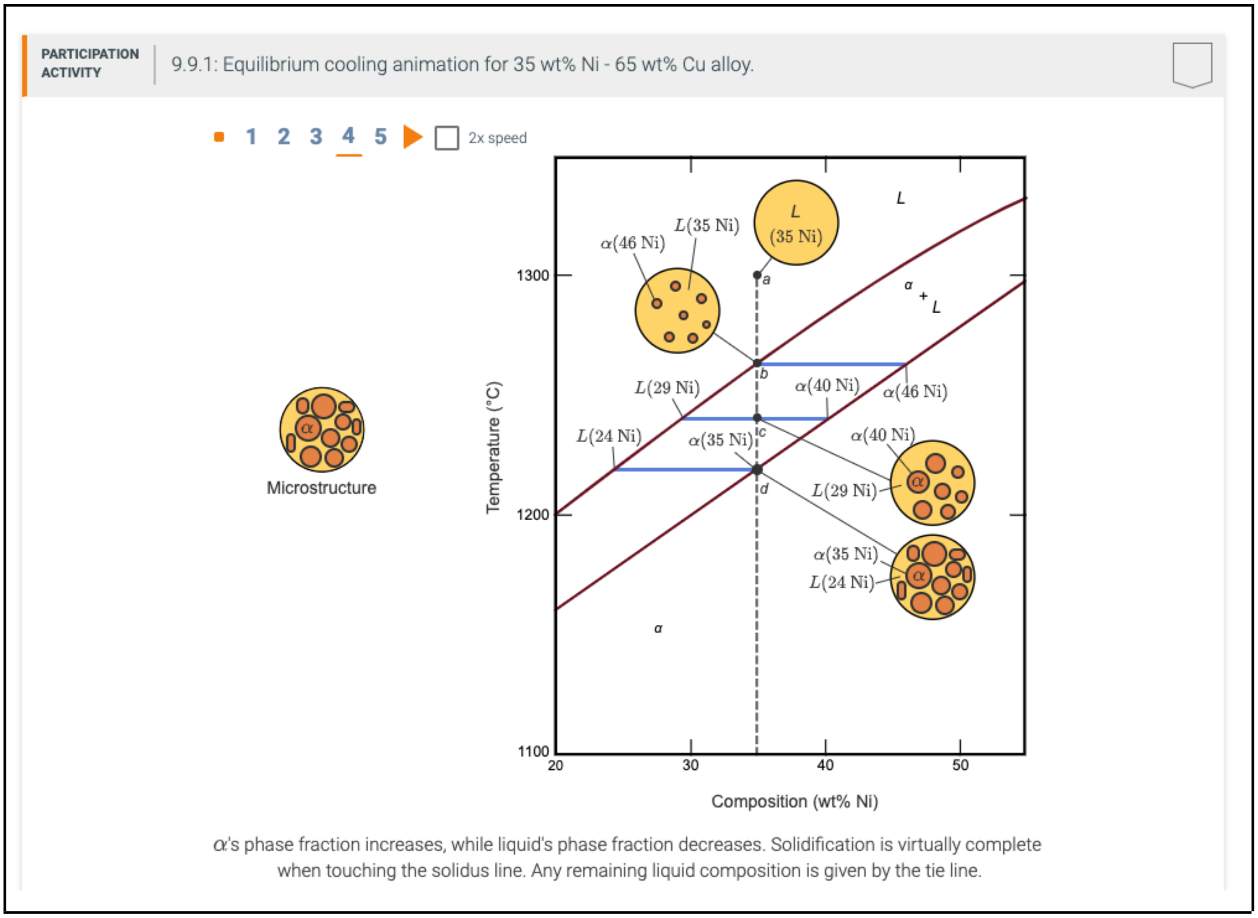
The first solid α microstructure forms at the liquidus line. The composition for α and liquid phases are given by a tie line.



PARTICIPATION ACTIVITY

9.9.1: Equilibrium cooling animation for 35 wt% Ni - 65 wt% Cu alloy.

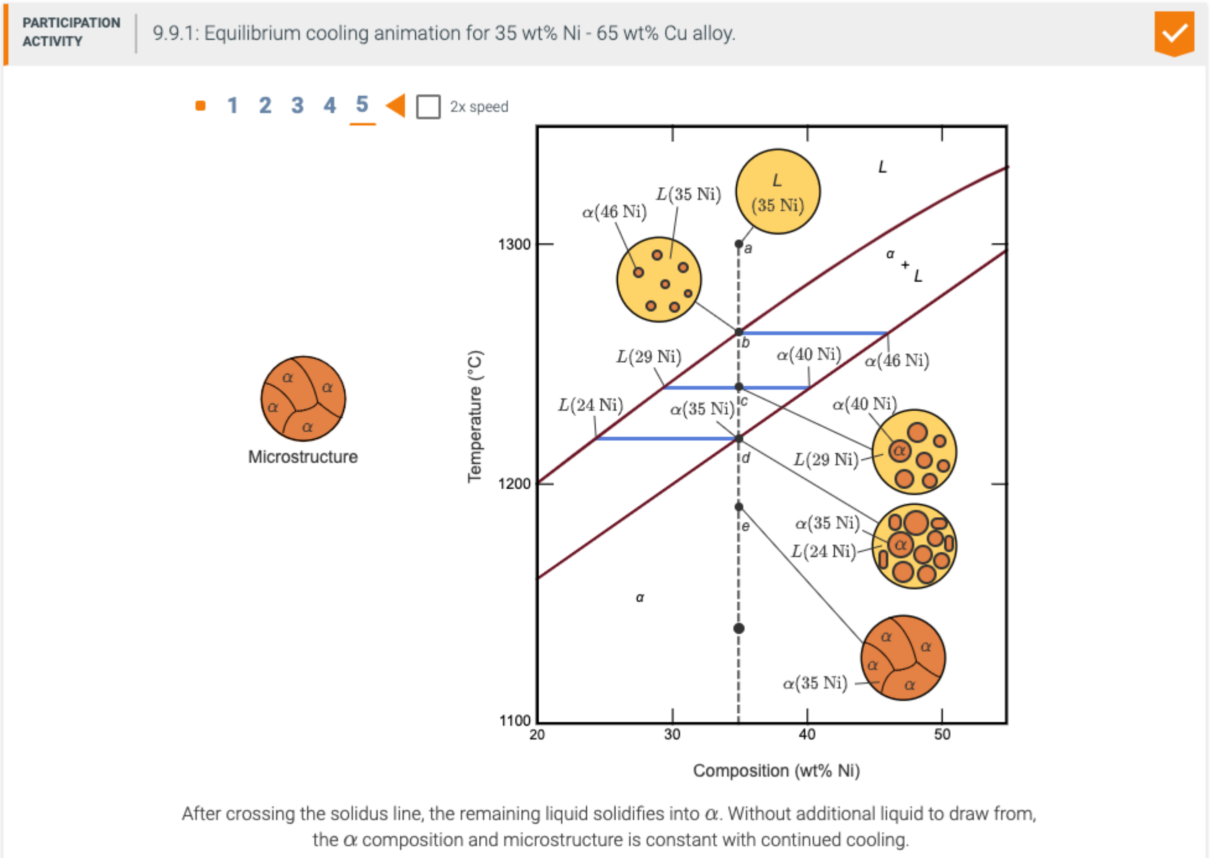
As cooling continues, the α microstructure's size grows. Both liquid and α compositions change, determined by the tie line at each temperature.



PARTICIPATION ACTIVITY

9.9.1: Equilibrium cooling animation for 35 wt% Ni - 65 wt% Cu alloy.

α's phase fraction increases, while liquid's phase fraction decreases. Solidification is virtually complete when touching the solidus line. Any remaining liquid composition is given by the tie line.



PARTICIPATION ACTIVITY | 9.9.1: Equilibrium cooling animation for 35 wt% Ni - 65 wt% Cu alloy.

After crossing the solidus line, the remaining liquid solidifies into α. Without additional liquid to draw from, the α composition and microstructure is constant with continued cooling.

New alt text	"Animation caption: Equilibrium cooling animation for 35 wt% Ni - 65 wt% Cu copper-nickel alloy, shows a temperature versus composition graph from 1100 to 1350 degree Celsius on the y-axis and 20 to 60 percent nickel alloy composition on the x-axis, along with phase boundary lines. The animation shows an alloy at 35 wt% nickel that is initially at a very high temperature in the liquid phase region. As the alloy cools, solid alpha begins to form. The formed solid alpha's composition is found using a horizontal tie line between the phase boundaries and the alloy's composition-temperature coordinate. As cooling continues, more solid alpha forms, and the solid alpha nickel composition increases as the liquid nickel composition decreases. When cooled below the solidus phase line, the alloy composition and formed solid alpha have the same composition, 35 wt% nickel. Static view (final step): A zoomed in version of the copper-nickel phase diagram unveils. The y-axis shows temperature from 1100\(^{\circ}\)C to 1400\(^{\circ}\)C. The x-axis shows the nickel concentration from 20 wt% Ni to 60 wt% Ni. The solidus line extends from about 20 wt% Ni, 1150\(^{\circ}\)C to about 60 wt% Ni, 1295\(^{\circ}\)C. The liquidus line extends from about 20 wt% Ni, 1200\(^{\circ}\)C to about 60 wt% Ni, 1350\(^{\circ}\)C. An alloy composition is shown as a dotted vertical line at 35 wt%Ni-65 wt% Cu. The alloy composition is shown to cool from Point a to point e. Point a is at 35 wt%Ni, 1300\(^{\circ}\)C. Point b is at 35 wt%Ni, 1260\(^{\circ}\)C. Point c is at 35 wt%Ni, 1240\(^{\circ}\)C. Point d is at 35 wt%Ni, 1220\(^{\circ}\)C. Point e is at 35 wt%Ni, 1175\(^{\circ}\)C. Tie lines are used for b, c, and d to determine phase compositions. CIrcular insets show the alloy's microstructure during cooling. The size of solid alpha that forms increases as cooling continues below the liquidus line, until no liquid remains below the solidus line and there is only solid alpha.

1: Step caption: The first solid \(\alpha\) microstructure forms at the liquidus line. The composition for \(\alpha\) and liquid phases are given by a tie line.

Animation action:
To the left of the figure, a circle labeled 'Microstructure' appears. A large black dot appears at point a, along with label 'a'. A COPY of the empty circle moves to point a. Text appears in the circle "L (35 Ni)".

A small black dot is left at point a, as the large black dot moves downward towards the liquidus line but does not touch the liquidus line.

2: Step caption:The first solid \(\alpha\) microstructure forms at the liquidus line. The composition for \(\alpha\) and liquid phases are given by a tie line.

Animation action: The Black Dot moves to be on top of the liquidus line, and the label point b appears. Inside the Microstructure Circle, seven very small orange circles, the new alpha growth, begin to appear. A Copy of the Microstructure Circle (and contents) Moves to connect to point b. A horizontal blue tie line appears. On the right hand side of the blue line that connects to the solidus line, \(\alpha (46 Ni) \) appears, indicating the alpha composition.. A copy of \(\alpha (46 Ni) \) text moves to the new Microstructure Circle, and points to the formed alpha inside the circle.

To the side of point b, \((35 Ni) \) appears, indicating the liquid composition. \((35 Ni) \) text then moves to the COPY Microstructure Circle, and points to the yellow liquid.

3: Step caption: As cooling continues, the \(\alpha\) microstructure's size grows. Both liquid and \(\alpha\) compositions change, determined by the tie line at each temperature.

Animation action: Animation action: A smaller black dot is left behind at point b, while the large black dot moves downward to point c. At the same time, the orange circles inside the original Microstructure Circle enlarge further. A COPY of the NEW Microstructure moves to connect to point c. After a brief pause, a new horizontal blue tie line appears. On the tie line's right hand side connected to the solidus line, \(\alpha (40 Ni) \) appears. A COPY of \(\alpha (40 Ni) \) moves to the new microstructure circle, and points to the inner orange alpha circle. On the tie line's left hand side connected to the liquidus line, \(L (29 Ni) \) appears. A COPY of \(L (29 Ni) \) text moves to the new microstructure circle, and points to the liquid.

4: Step caption:\(\alph\)'s phase fraction increases, while liquid's phase fraction decreases. Solidification is virtually complete when touching the solidus line. Any remaining liquid composition is given by the tie line.

Animation action: A smaller black dot is left behind at point c, while the large black dot moves downward to point d. At the same time, the orange circles inside the original Microstructure Circle enlarge again, along with additional formed microstructure shapes. A COPY of the NEW Microstructure moves to connect to point d. After a brief pause, the blue tie line appears. On the tie line's right hand side connected to the solidus line, \(\alpha (35 Ni) \) appears. \(\alpha (35 Ni) \) moves to the new microstructure circle, and points to the inner orange alpha material.

	On the lowest tie line's left hand side connected to the liquidus line, \(L (24 Ni) \) appears. A COPY of \(L (24 Ni) \) moves to the new microstructure circle, and points to the liquid. 5: Step caption:After crossing the solidus line, the remaining liquid solidifies into \(\alpha\). Without additional liquid to draw from, the \(\alpha\) composition and microstructure is constant with continued cooling. Animation action: A smaller black dot is left behind at point d, while the large black dot moves downward to point e. At the same time, the orange circles inside the original Microstructure Circle enlarge again, and overlap so completely fill the MC circle [no liquid visible]. Next, a COPY of the Microstructure Circle and contents moves to connect to point e. \(\alpha (35 Ni) \) appears at point e. \(\alpha (35 Ni) \) moves to the final microstructure circle, and points to the inner alpha material. The dot continues to move downward, but there is no change in the microstructure."